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Draft Environmental Impact Statement for Sludge Disposal and Land Reclamation in Fulton County, Illinois

Environmental Protection Agency, Chicago, Ill Region V

Prepared for

Enviro Control, Inc, Rockville, Md

Jun 76

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U.S. ENVIRONMENTAL
PROTECTION AGENCY
REGION V

ENVIRONMENTAL IMPACT STATEMENT

DRAFT

Sludge Disposal and Land Reclamation in Fulton County, Illinois

June 1976

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16. ABSTRACT

This draft environmental impact statement deals with the land application of sludge by the Metropolitan Sanitary District of Greater Chicago in Fulton County, Illinois. The project, known as the Prairie Plan, began in 1971 with local funding. The statement outlines socio-economic considerations, land use, agricultural benefits, and transportation costs. The primary and secondary impacts of reclamation of strip-mined land through application of nutrients and organic matter produced through wastewater reclamation are addressed. A description of the monitoring system, loading rates, and land application methodologies are included. Direct and indirect health effects of the project are also presented.

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FOR
SLUDGE DISPOSAL AND LAND RECLAMATION
IN FULTON COUNTY, ILLINOIS

Prepared By The
UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
REGION V
CHICAGO, ILLINOIS

With The Assistance Of
ENVIRO CONTROL, INC.
ROCKVILLE, MARYLAND

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DEPUTY REGIONAL ADMINISTRATOR

JUNE 1976

SUMMARY SHEET

(X) Draft

( ) Final

U.S. Environmental Protection Agency Region V, Chicago

1. (X) Administrative Action

   ( ) Legislative Action

2. Description of the Action

An analysis of the methodologies utilized by the Metropolitan Sanitary District of Greater Chicago for the application of sludge on strip mined land in Fulton County, Illinois is presented. Since the project is already being implemented, this statement uniquely presents the current and projected impacts of continued operations. Digested sludge is loaded at MSDGC's West-Southwest Treatment Plant in Stickney, Illinois and barged approximately 200 miles down the Illinois River to Liverpool. From the Liverpool dock the sludge is pumped out and relayed 10 miles via underground pipeline to the project holding basins for storage. Dredge equipment is used to mix the sludge to a uniform consistency and solids content of 6% or less before pumping from the basins into the distribution system.

Sludge is applied from early spring to late fall utilizing a traveling sprayer and a soil injection system. The spray application system is scheduled to be phased out.

Each field receiving sludge has been contoured to allow collection of runoff due to storm events or application. Environmental control systems are employed to monitor surface and ground water, soil and rock, plants and aquatic biota, and the atmosphere.

3. Environmental Impacts

a. Water

Contamination of surface water has occurred at the project site due to runoff from sludge application to fields and release of effluents from field retention basins. Retention basins were found to have insufficient capacity and therefore ineffective in removing suspended solids resulting in siltation and excess dissolved oxygen depletion in receiving waters. However, runoff from strip-mined areas and effluents from septic tanks and the sewage treatment plant also contribute to this pollution. Groundwater, as sampled at wells and springs, has not been degraded by the application of sludge. However, groundwater is significantly contaminated from natural geochemical sources, particularly by exposure from past strip-mining.

b. Soils

Sludge has a beneficial effect upon the physical properties of soils. The high organic content of sludge provides a matrix for formation of a stable soil structure. Incorporation of sludge into soils by either disking after spray application or direct injection decreases the chance for runoff and erosion. Soil loading rates will be determined based upon heavy metals as limiting factors.

c. Odors and Noise

Complaints of offensive odors have arisen from citizens within a 4 to 5 mile area surrounding the sludge application sites and holding basins. The malodorant is generated as an earthy smell. The prevailing winds at the project site are south to southwest dispersing the airborne odorants along the northerly perimeter of the MSDGC property.

A reduction in malodorants will occur due to the modification of application to soil injection. This malodorant reduction will be directly attributable to the reduction of aerosols.

Noise generated at the Liverpool dock includes the noise associated with barge manuvering and booster pumping. These activities increase the ambient noise levels around the community of Liverpool. Noise levels at the site are attributed to tractors and sludge sprayers. These noise levels can be detected at the perimeter of the project site. These noise levels are similar to existing agricultural noises in magnitude and duration.

d. Health Effects

Among all methods of sludge application, pressurized spraying offers the greatest potential for direct transfer of hazardous components to humans or animals. Inhalation of sludge aerosols possibly containing pathogens or toxic substances presents an opportunity for protracted and repetitive exposure. The lack of reported cases of health effects with Fulton County may indicate that the level of risk associated with sludge application is low, rather than non-existent.

Indirect effects are caused by the consumption of plants or animals that have been contaminated by heavy metals. The interactions among sludge components and the food chain are complex and information concerning the ability of each trophic level to accumulate toxic compounds and pass them on to succeeding trophic levels is sparse and qualitative at best. The most likely suspects for potential hazard are arsenic, cadmium, lead, mercury, and selenium. Both sludge and soil at the project site are high in cadmium, especially in relation to zinc. Cadmium enrichment may be the most limiting single factor in sludge loading rates.

The actual indirect hazard to humans would stem from the future use of reclaimed strip-mined land for cropping or livestock grazing, possibly resulting in a majority of a family's food intake being contaminated by trace elements.

e. Socio-economic Effects

The most obvious short-term local economic effect of the project has been to create jobs for approximately 120 skilled and unskilled contract laborers who average 6 to 8 months of employment yearly.

The sludge application project has also affected the local public finance by increasing future market value of the land and the tax base.

f. Land Use

Levelling and grading of strip-mined sections of the project site to prepare the sludge application fields have increased the suitability of the land for agriculture. The removal of surface rocks and levelling of steep slopes have also considerably increased suitability for recreational use including playgrounds, campsites, recreation building sites, roads, and trails.

4. Alternatives Considered

The alternatives that were examined by MSDGC in development of the project are divided into five subsystems which include various options. The subsystems are:

A. Sludge Dewatering Subsystems

1. Air drying on sand beds
2. Thickening by gravity sedimentation or flotation
3. Dewatering by centrifugation and vacuum filtration
4. Dual cell gravity dewatering and freezing-thaw technique
5. Use of moving filter screens or a belt-filter press or vertical screw press

B. Sludge Stabilization Subsystems
   1. Heated anaerobic digestion
   2. Imhoff digestion
   3. Incineration
   4. Heat drying
   5. Wet air oxidation
C. Sludge Disposal Subsystems
   1. Sanitary landfill
   2. Lagooning
   3. Ocean dumping
D. Sludge Utilization Subsystems
   1. Fertilizer production
   2. Composting
   3. Soil reclamation
E. Sludge Transportation Subsystems
   1. Truck transportation
   2. Rail transportation
   3. Barge transportation
   4. Pipeline transportation

5. Federal, State, and Local Agencies and Individuals Notified of This Action

Federal

- Senator Adlai E. Stevenson, III
- Senator Charles H. Percy
- Representative Thomas Railsback
- Representative Robert Michel

Council on Environmental Quality

Environmental Protection Agency

- Office of Federal Activities
- Office of Public Affairs
- Office of Water Programs Operations
- Environmental Evaluation Branch

Department of Interior

- Bureau of Outdoor Recreation
- Fish and Wildlife Services
- Office of Environmental Project Review

Department of Defense

- Army Corps of Engineers
- North Central Division
- Chicago District Office

Department of Agriculture

- Soil Conservation Service

Department of Health, Education, and Welfare

State

- Governor of Illinois
- Illinois Institute for Environmental Quality
- Illinois Environmental Protection Agency
- Illinois Department of Transportation
- Illinois Division of Waterways
- Illinois Division of Water Pollution Control
- Illinois Department of Conservation
- University of Illinois

Local

- Fulton County Board
- Fulton County Board of Health
- Fulton County Medical Society
- Spoon River College
- Metropolitan Sanitary District of Greater Chicago
- City of Canton
- City of Lewistown
- Village of Bryant
- Village of St. David
- Village of Cuba
- League of Women Voters of Cook County
- Natural Land Institute

Others

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The Council on Environmental Quality:	June 17, 1976
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FOREWORD

Unlike most Environmental Impact Statements, this Draft EIS does not concentrate on the details of a particular project or group of projects, but rather is meant to evaluate the cost-effectiveness and environmental compatibility of sludge application on strip-mined land in Fulton County. The grant applicant for this sludge application/land reclamation program is the Metropolitan Sanitary District of Greater Chicago (MSDGC). In January, 1975 the MSDGC submitted an eight-volume facilities plan to Region V. Included in this facilities plan was the sludge application program which is the subject of this Draft EIS.

It should also be pointed out that the MSDGC has been implementing this program, known as the Prairie Plan, since 1971 without federal funding. The nature and extent of future federal participation in the Fulton County program will depend, in part, upon the conclusions reached in this EIS.

It should also be emphasized that the total MSDGC sludge preparation and disposal program is not within the purview of this impact statement. The ancillary sludge preparation processes and programs are only included to the extent that they influence the quality of sludge transported to the Fulton County site.

Chapter One has been prepared to give an overview to the reader of the major findings. More detailed discussions can be found in the subsequent chapters.

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I. SUMMARY AND CONCLUSIONS

This chapter presents the major findings of this report. The presentation begins with a summary description of the existing Fulton County project and a discussion of the cost-effectiveness of alternative sewage sludge treatment and disposal processes, which conveys the overall attractiveness of sludge application to land as compared to other system options. It continues with a summary of the present environmental and socio-economic conditions that are related to the assessment of known or predicted project impacts. The known and potential environmental and socio-economic effects of the project are then reviewed. Once the potential hazards or risks have been recognized, the presentation concludes by recommending precautions or safeguards that should be employed in future project operations. Further monitoring and analysis required to fill information gaps are suggested.

A. EXISTING PROJECT SITE AND OPERATIONS

The Fulton County land reclamation project site is located centrally in Fulton County, which is situated in the upper region of the Spoon River watershed in west central Illinois (Figure I-1). Before the project was conceived, approximately 45,000 acres or 60% of the land in Fulton County had been strip-mined, and the county was adding to this at a rate of 1,200 to 2,000 acres per year. On October 30, 1970 the Metropolitan Sanitary District of Greater Chicago (MSDGC) purchased 5,461 acres of land from a private source and made arrangements with county and state agencies for sewage sludge application to portions of the site. As of August 1975, the MSDGC owned 15,528 acres of land in Fulton County. The Sanitary District does not anticipate any future significant land purchases upon fulfilling the development plans for the present land holdings.

Construction work began in January 1971. Since that time, the project site has been contoured and terraced to create fields suitable for sludge application. Between 1971 and 1973, 43 application fields were developed, ranging in size from 15 to 150 acres. Four large holding basins have been constructed to store sludge before application to the fields.

The operations begin when digested sewage sludge from the MSDGC West-Southwest Treatment Plant or sludge from the Lawndale lagoons, or a mixture, is barged approximately 200 miles down the Illinois River to the dock at Liverpool in Fulton County. The sludge is pumped out and relayed 10 miles by booster pumps to the project holding basins for storage. Dredge equipment is used to mix the sludge to a uniform consistency and solids content of 6% or less before pumping from the holding basins into a piped distribution system.

The sludge is applied to the soil by a traveling sprayer, a moldboard plow or tandem disk incorporator, a soil injector mounted on a tank truck, or gated irrigation pipe. Spraying is accomplished by modular units consisting of pumps, an above-ground header system, and a "big gun" spray vehicle. Liquid sludge is sprayed at a rate of 600 gpm, a pressure of 90 psi, and a horizontal throw of 120 to 150 ft. The tandem disk incorporator applies sludge to the entire cross-sectional area of the soil, using a disking machine with a distribution manifold that directs sludge to each disk while tilling the soil. The soil injector works on the same principle as the incorporator, except that the injector applies sludge into slots formed in the soil by a tool shank. With the gated irrigation pipe, the slotted pipe is laid on high ground and liquid sludge is pumped through the slots.

Sludge is applied from early spring to late fall, at a maximum rate in May. Approximately 553 dry tons of sludge were applied to about 207 acres of land in 1972. Sludge application rates and the total tonnage of sludge applied in 1973 through 1975 are shown in Table I-1 (p. III-16).

To protect against environmental degradation resulting from the project, the sludge holding basins were lined to prevent groundwater seepage, control berms and retention basins were installed to contain storm runoff and control field effluent quality, and the fields were graded to reduce runoff velocity, erosion and sedimentation. The effectiveress of environmental control systems and the environmental soundness of project operations are monitored by five systems pertaining to sludge, surface and ground water, soil and rock, plants and aquatic biota, and the atmosphere.

A sludge analysis program is designed to ensure adequate treatment of the sludge before shipment to the holding basins. The water monitoring system includes sampling, analysis, data reduction and reporting. Prior to initial project operations, 52 soil borings were made to bedrock; these will be compared with another set of borings to be made in 1977. Ecological and biochemical studies are being conducted to determine effects of sewage sludge application. In addition, a meteorological station was set up close to the holding basins to measure air temperature, wind speed and direction, relative humidity, rainfall, and atmospheric ammonia concentration. From its beginning in 1971 through March 1975, every aspect of project operations was performed under permits issued by the Illinois Environmental Protection Agency and the Fulton County Health Department. The Fulton County Planning Commission reviews all land use plans and requests modifications or gives approval.

B. COST-EFFECTIVENESS OF ALTERNATIVE METHODS OF SLUDGE PROCESSING AND DISPOSAL

The sludge processing and disposal methods currently practiced by the MSDGC represent nearly the full spectrum of system alternatives. Included in the body of this report is a careful analysis of ten system options which were derived by the MSDGC from various combinations of subsystems for sludge dewatering, stabilization, disposal, utilization, and transportation. The ten systems chosen for analysis are delineated in Figure I-1.

The cost-effectiveness of a system represents a balance between capital, operating and maintenance costs, system reliability, environmental impacts, and costs for measures effected to prevent or mitigate the potential environmental hazards or risks. The only component in this balance for which actual values can be assigned is total annual costs, excluding the cost of extraordinary mitigating measures. Environmental impacts can be assessed only in terms of relative potential impacts from each system alternative, as the state of the art has not progressed to the point of reliably assigning monetary or other exact values to environmental effects.

Table I-1 summarizes the total annual costs, limits to reliability, relative environmental impacts, and relative major mitigation costs for each system alternative. The ratings in this table are strictly judgmental, and are based on a review and synthesis of subsystem characteristics.

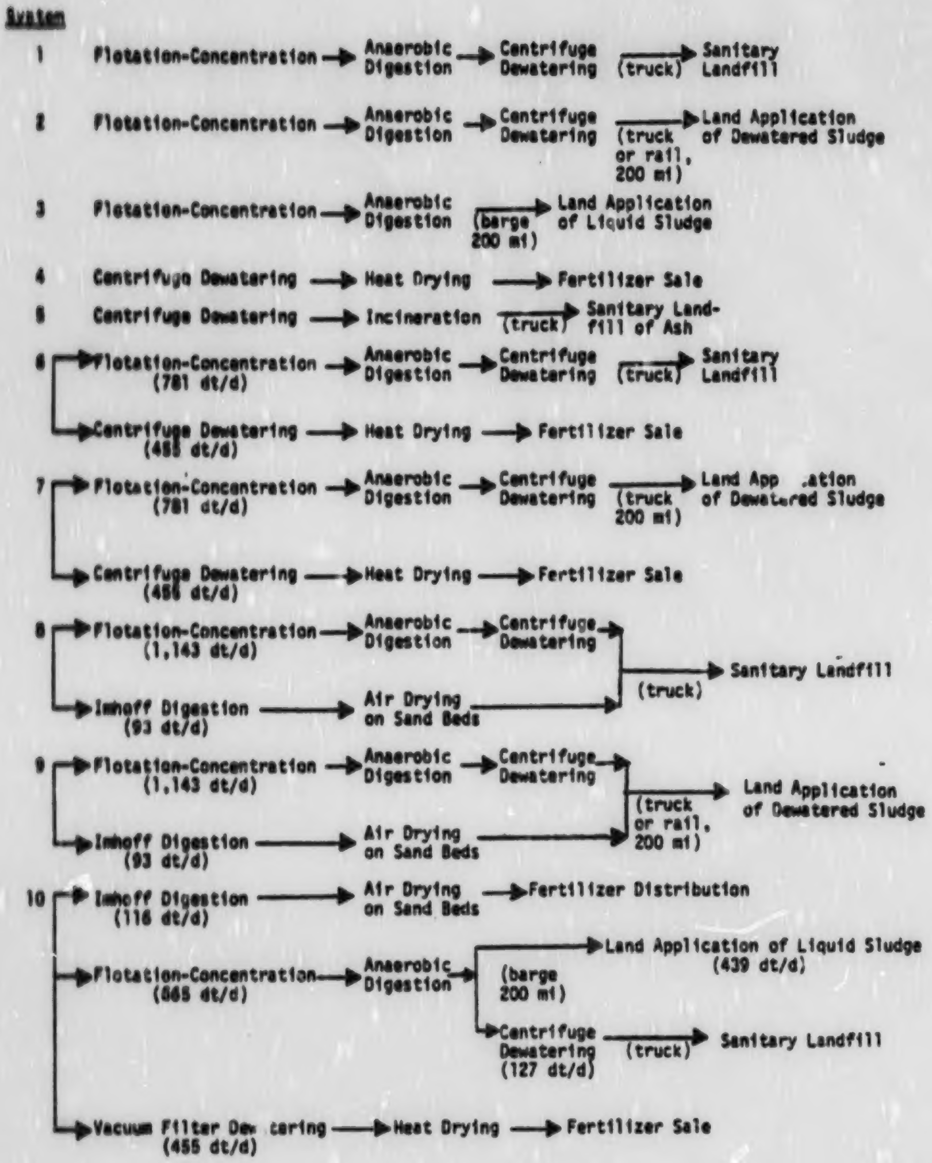
System
1
Flotation-Concentration
Anaerobic Digestion
Centrifuge Dewatering
(truck)
Sanitary Landfill
2
Flotation-Concentration
Anaerobic Digestion
Centrifuge Dewatering
(truck or rail, 200 mi)
Land Application of Dewatered Sludge
3
Flotation-Concentration
Anaerobic Digestion
(barge 200 mi)
Land Application of Liquid Sludge
4
Centrifuge Dewatering
Heat Drying
Fertilizer Sale
5
Centrifuge Dewatering
Incineration
(truck)
Sanitary Landfill of Ash
6
Flotation-Concentration (781 dt/d)
Anaerobic Digestion
Centrifuge Dewatering
(truck)
Sanitary Landfill
Centrifuge Dewatering (455 dt/d)
Heat Drying
Fertilizer Sale
7
Flotation-Concentration (781 dt/d)
Anaerobic Digestion
Centrifuge Dewatering
(truck 200 mi)
Land Application of Dewatered Sludge
Centrifuge Dewatering (455 dt/d)
Heat Drying
Fertilizer Sale
8
Flotation-Concentration (1,143 dt/d)
Anaerobic Digestion
Centrifuge Dewatering
Imhoff Digestion (93 dt/d)
Air Drying on Sand Beds
(truck)
Sanitary Landfill
9
Flotation-Concentration (1,143 dt/d)
Anaerobic Digestion
Centrifuge Dewatering
Imhoff Digestion (93 dt/d)
Air Drying on Sand Beds
(truck or rail, 200 mi)
Land Application of Dewatered Sludge
10
Imhoff Digestion (116 dt/d)
Air Drying on Sand Beds
Fertilizer Distribution
Flotation-Concentration (865 dt/d)
Anaerobic Digestion
(barge 200 mi)
Land Application of Liquid Sludge (439 dt/d)
Centrifuge Dewatering (127 dt/d)
(truck)
Sanitary Landfill
Vacuum Filter Dewatering (455 dt/d)
Heat Drying
Fertilizer Sale

Figure I-1. System Operations and Sludge Flows (MSDGC 1975a)

Table I-1. Ratings of Alternative Systems (Enviro Control, Inc., 1975)

Alternative	Total Annual Costs $(x10^6)$	System Reliability Limits	Potential Adverse Environmental Impact Energy Consumption	Air Pollution	Water Pollution	Soil Contamination	Composite Impact	Impact Mitigation Costs
1	$31.67	Slight	Slight	Slight	Slight	Slight	Slight	Moderate
2	$50.06	Moderate	Moderate	Slight	Moderate	Substantial	Moderate	Substantial
3	$44.98	Substantial	Slight	Slight	Substantial	Substantial	Moderate	Substantial
4	$32.82	Substantial	Substantial	Substantial	Slight	Slight	Moderate	Substantial
5	$22.83	Moderate	Substantial	Substantial	Slight	Slight	Moderate	Substantial
6	$28.77	Moderate	Moderate	Moderate	Slight	Moderate	Moderate	Moderate
7	$37.50	Substantial	Moderate	Moderate	Moderate	Substantial	Moderate	Moderate
8	$31.52	Slight	Slight	Slight	Slight	Moderate	Slight	Moderate
9	$49.91	Moderate	Slight	Slight	Moderate	Substantial	Moderate	Substantial
10	$35.19	Substantial	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate

C. CURRENT CONDITIONS OF THE ENVIRONMENT

This discussion of current environmental conditions provides baseline information only for those present conditions that are directly related to environmental impacts of the project. For instance, population data are excluded from this summary because the project should not significantly influence the population size or composition of Fulton County. Further, the suitability of the project site for industrial location will not be covered because there will be little or no demand for industrial reuse of the project site. The topics covered are climate and topography, geology and soils, hydrology and water quality, biology and ecosystems, and socio-economic and land use settings.

1. Climate and Topography

The climate of the project area is typically continental. The most probable weather conditions are a neutral atmosphere (Pasquill Stability Class D) and southerly winds at 10.2 mph. Worst conditions, in terms of air pollution potential from sludge odors, are a calm atmosphere with a mixing height of less than 100 meters and a wind speed of less than 1 mph. With regard to soil erosion, sedimentation, and water quality problems from sludge runoff, the 24-hour, 100-year storm represents the worst condition, producing a rainfall of 6.53 inches.

One consequence of the large-scale strip mining operations in Fulton County is an extremely rough topography, presenting a barrier to full land reclamation and re-use. Strip mining has left steeply sloping spoil mounds which may increase the capacity of storm runoff to carry suspended solids into receiving waters. Mining has also resulted in a number of long, narrow lakes, which have probably altered the distribution of thermal energy at the site and, therefore, the microclimate. Availability of moisture from lake evaporation, coupled with nighttime loss of thermal energy from the bare surface, may encourage the formation of ground fogs, limiting mixing in the surface layer and contributing to accumulation of sludge malodorants near the ground.

2. Geology and Soils

During surface mining, the overburden soils and cap rock were removed. The subsurface of strip-mined areas consists of cohesive fine-grained soils with pockets and discontinuous zones of boulder-size rock. The rearranged and redistributed overburden soils are rather impervious, minimizing the potential for groundwater contamination from sludge, but increasing surface runoff and potential surface water contamination. However, some zones or layers may consist of broken shale and sandstone slabs or blocks arranged in a way that provides for rapid infiltration of surface water. Such formations create a mechanism for groundwater pollution.

In areas where no strip mining has occurred, the glacial soils are covered by loess. This material is essentially impervious, but is subject to erosion if exposed on slopes steeper than 20%. Mineral deposits such as black shale, which are exposed by strip mining, create high background levels of trace elements, compounding the potential for water pollution from sludge. For example, both sludge and black shale contribute significantly to water pollution from cadmium. While their respective contributions are additive, they cannot be distinguished without very precise soil investigations.

3. Hydrology and Water Quality

Most of the surface water at the project site is drained by Big Creek and Slug Run, a branch of Big Creek, to Spoon River, a tributary of the Illinois River. Surface water is an extremely important resource in Fulton County because groundwater concentrations of dissolved minerals make the groundwater an unsuitable source for public water supply. Steep slopes, sparse vegetative cover and poor soil permeability create high runoff volume and velocity, causing erosion and stream or lake siltation which is a hazard to aquatic biota. The high suspended solids content of sludge could add to this condition if it is not contained within the application fields.

Baseline (1971) concentrations of chloride, cadmium, chromium, manganese, mercury, nickel, and zinc in streams were generally in conformance with Illinois water quality standards. Standards were occasionally violated for sulfate, copper, and lead. High background levels of some heavy metals make surface waters vulnerable to increased violations from metal additions contributed by sludge. Ammonia nitrogen, iron, and fecal coliform concentrations violated standards in Big Creek. For instance, ammonia nitrogen levels as high as 8.1 mg/l were measured at a station on Big Creek, compared to the state standard of 1.5 mg/l. Concentrations of iron were as high as 4.8 mg/l, as opposed to the standard of 1.0 mg/l.

A study of baseline groundwater quality in the project area indicated that concentrations of chromium, copper, iron, lead, manganese, and nickel were within the range found elsewhere in the United States. Ranges of pH and zinc concentrations were close to national values, but those of chloride, sulfate, calcium, magnesium, and sodium were higher, indicating that dissolved solids or salt concentrations were excessive. High overall concentration of dissolved minerals, approximately three times the U.S. standard of 500 ppm, could necessitate expensive treatment of groundwater to achieve compatibility as a public water supply source.

4. Biology and Ecosystems

A great variety of aquatic and terrestrial wildlife currently inhabits the project area and fish abound in most of the local lakes. The relevance of existing fish and wildlife to disposal of sludge in their habitats is that biomagnification of toxic substances in sludge through the food chains of wild populations cannot be controlled as well as in the case of domestic animals.

Six rare and endangered animal species are listed for U.S. EPA Region V, containing Illinois. Fish species are the longjaw cisco and the blue pike. Endangered birds are the arctic peregrine falcon and Kirtland's warbler. Mammals are the Indiana bat and the eastern timber wolf. The likelihood that any of these are present at the project site is extremely remote. According to biologists of the Natural History Survey in Urbana, Illinois, there are three endangered plant species which probably exist in the project area. One, an endangered woodland species, is Aster chasei, a woodland aster. Two endangered prairie species are Lespedeza leptostachya, a bush clover found on dry prairie, and Petalostemum foliosum, a prairie clover found near river banks.

5. Socio-Economic and Land Use Conditions

Although it has been estimated that the project will have only a small effect upon socio-economic conditions, socio-economic trends are important in determining the future demand for various uses of land in the project area. According to present trends, demand for farmland in Fulton County has been decreasing, and future increased demand should be slight. This decline reflects the influence of advanced technology in replacing labor with capital-intensive methods of production. Local agriculture is also changing in composition. Dairy, winter wheat and poultry production are declining, while corn, soybeans, swine and beef cattle production have increased. Thus, future land use in the project area will probably be centered more on forage crops, pasture and feedlots than plant or animal produce.

Suitability of strip-mined land in the project area for various uses is affected by topography, soils, and drainage. Problems of settlement with unconsolidated soils in the strip-mined sections of the project site could make it prohibitively expensive to build hard surface roads, underground utilities, and residential or industrial structures. Current levels of available plant nutrients and organic matter make these soils unsuitable for intensive agriculture. Without land reclamation utilizing sewage sludge, any row-crop production on formerly strip-mined fields would depend on liberal use of costly chemical fertilizers, extensive soil conditioning, and rigorous conservation practices. Steep slopes and severe problems of access in unreclaimed strip mining areas have caused failure of previous attempts to manage timber crops in Fulton County.

The recreation potential of the project area would be limited by poor accessibility and competition from the diverse attractions in nearby Spoon River Valley, along the Illinois River, at Dickson Mounds State Park, and in the numerous former strip-mined areas where recreation uses are of particular interest.

Large tracts of equally available and suitable land in Fulton County are expected to keep land values low in the project area. According to tax assessment records, reclaimed strip-mined lands which are used productively have been valued only 25% more than unreclaimed lands.

D. SIGNIFICANT SOCIO-ECONOMIC AND ENVIRONMENTAL EFFECTS OF THE PROJECT

This section summarizes the potential socio-economic and environmental effects associated with the project, and identifies observed effects whenever possible. In the absence of documented evidence, the assessment relies on theory such as a mathematical model for predicting downwind dispersion of sludge aerosols or odorants, or on findings inferred from the general scientific literature and data on projects elsewhere. The first part of this section deals with socio-economic and land use effects, and the second part addresses environmental effects and human or animal health effects.

1. Socio-Economic and Land Use Effects

This discussion begins with an assessment of the project's influence on the suitability of the land for a variety of potential uses. The project has affected land suitability both through the preparation of land for sludge application, and by sludge application itself. The discussion concludes with a brief description of socio-economic effects of the project.

a. Land use effects - Levelling and grading of strip-mined sections of the project site to prepare the sludge application fields, and the removal of large rock fragments from the surface, have increased the suitability of the land for a number of uses. Beyond the obvious benefits to agriculture, levelling has made it possible to use farm machinery to control tree growth, instead of employing hand labor which is prohibitive in cost. However, the relatively small size and discontinuity of the application fields do not lend well to large-scale mechanized farming. Drainage control systems developed with the application fields have increased land suitability for potentially polluting uses, such as livestock feedlots and intensive crop production involving high application rates of fertilizers and pesticides. The removal of surface rocks and levelling of steep slopes have also considerably increased suitability for recreational use including playgrounds, campsites, recreation building sites, roads, and trails.

Sludge application has multiple effects upon land use, both during and after termination of its use in reclaiming land. Nuisances associated with sludge application have a short-term negative influence upon residential expansion in nearby rural settlements. The primary nuisance is from the odors emanating from sludge holding basins and from airborne dispersion of sludge spray during spraying operations; the general visual blight created by spraying sludge is another. Another liability is that many extremes of weather and the presence of crops during the growing season interfere with sludge spraying or disking, perhaps reducing loading rates to uneconomic levels. Crop rotation would also curtail the amount of sludge applied. High rates are necessary both to economic sludge disposal and high crop yields. In addition, potentially toxic accumulations of certain organic compounds and trace elements in soil from prolonged sludge application might hinder future agricultural use of the land by affecting crop yields.

On the other hand, benefits are derived from the addition of nutrients and organic matter to soils. Soil enrichment may favor future intensive row-crop farming. It is likely that sludge application has only slightly increased the nutrient and organic contents in soil of the 1,000 acres of former place land (undisturbed by strip mining), and will affect the productivity of these presently fertile fields only marginally. However, the impact of the project upon agricultural activity in Fulton County hinges on the potential productivity of the 2,382 acres of formerly strip-mined land scheduled for sludge disposal. The future fertility of these fields can be expected to increase significantly with the continued application of sludge, possibly making row-crop production economically feasible.

Sludge application also influences opportunities for recreation benefit and conservation land use in a project area. Sludge application adds organic material and mineral nutrients in quantities sufficient for the growth of a greater diversity of plant species than are found on strip-mined lands reclaimed by other methods. Increased plant diversity generally leads to increased diversity in wildlife.

b. Socio-economic effects - The most obvious short-term local economic effect of the project has been to create jobs for approximately 120 skilled and unskilled contract laborers who average 6 to 8 months of employment yearly. In 1975, the MSDGC paid approximately $890,000 to their contract employees and $300,000 to their full-time staff of 23.

The sludge application project has also affected the local public finance by increasing future market value of the land and the tax base. In 1973, the MSDGC paid to Fulton County roughly $102,000 in real estate taxes, which amounted to 1.3% of total tax revenues, and $34,000 in personal property taxes which amounted to 3.4% of the total. Land reclamation and re-use could theoretically add about $152,450 to the market value of the 2,382 project acres of strip-mined land scheduled for sludge application.

Future uses of the land will not be economically intensive and would generate little on-site employment and income. Visitors to potential conservation or recreation sites could add some local income to tourist-related retail and service enterprises, but poor accessibility of the project area will limit this potential. Agricultural re-use, especially grazing, would have a small multiplier effect on local employment and income. Feedlots could contribute to the expansion of nearby meat packing firms. Full reclamation and agricultural re-use could theoretically add $100,000 to $200,000 per year (1970 dollars) to the ultimate value of agricultural output.

2. Environmental and Health Effects

Potential environmental effects of the project include air pollution from sludge malodorants, noise from equipment, surface and groundwater contamination from sludge runoff and seepage, and adverse changes in the physical and chemical characteristics of soils due to accumulation of minerals. Human health effects could result directly from the inhalation of sludge spray aerosols contaminated with pathogens and heavy metals, or indirectly, through the consumption of plants or animals similarly contaminated. Data reflecting actual violations of environmental standards or substandard project design, as well as project conformance, are used to bolster judgments based on findings from similar sludge experiments elsewhere.

a. Odors and noise - During the period of several years in which sludge application to land has been practiced in Fulton County, complaints of offensive odors have arisen from citizens near the project site. The Midwest Research Institute (MRI), under contract with the Fulton County Health Department, designed a program to narrow down the odor source to the MSDGC property, the Canton sewage treatment plant, a cattle feedlot, or the gob piles and septic tanks common to the area. By comparing the results of chromatographic analysis of samples collected at both the complaint sites and the possible sources, MRI determined the probability of the odors in question originating from MSDGC sources to be 0.71 or 71%. Although the malodorants in sludge have not been totally identified, they probably act synergistically to generate an earthy smell.

The odor impact area is contained within a circle with a radius of approximately 4 to 5 miles, including the communities of St. David, Bryant, Cuba, and the outskirts of southwest Canton. Considering the prevailing winds and likely dispersion pattern of airborne odorants, farm households along the northerly perimeter of the MSDGC property will experience most of the odor impact. Infrequent periods of severe impact could result from subsidence inversion which produces atmospheric stagnation and high air temperature. However, the joint frequency of a calm atmosphere, low mixing height, and light wind is only 0.27%, or approximately 24 hours in a year. Atmospheric dilution is considered ineffective in the abatement of odor problems; it is estimated to reduce odorant concentrations 4 miles downwind by approximately two to four times, depending on weather conditions.

Although the storage of sludge is likely to contribute substantially more odor emissions than its application to land, the respective contributions cannot be distinguished in atmospheric samples. If the emission strength of odors at the holding basins remains the same, odor complaints will probably continue to be raised no matter which application methods are employed.

Among the different application methods, pressurized spraying has the greatest odor potential. This is a direct result of the production of sludge aerosols, which tremendously increases the area of air-liquid interface on which evaporation of malodorants occurs. The odor emission potential of aerosols generated by the sprayer is approximately 50 to 100 times greater than any of the other application methods or from sludge-treated fields.

Surface spreading methods reduce odor potential significantly, because sludge aerosol formation is minimized and the exposed sludge surface area is limited to the land surface. Of the two surface spreading techniques examined, overland flow and infiltration-percolation, the latter has less odor potential. Surface penetration methods, including soil incorporation and soil injection, present the least odor problems. Neither of these techniques generates sludge aerosols, and the exposed surface area is much less with surface penetration than with surface spreading, because the soil behaves as an odor blanket when sludge is incorporated into it. Between soil incorporation and soil injection, the latter has less odor potential because injection further reduces exposed surface area. One drawback in both of these methods is their limited use during growing seasons.

The strength of odor emissions from evaporation of sludge applied to the soil surface and from surface ponding is equal to that from the sludge holding basins. The consequent odor problems are short-term, however, because most odorants in the sludge will be released into the atmosphere within the first week after sludge application. Nevertheless, these short-term impacts may be prolonged and intensified during unfavorable meteorological conditions.

The planned 1976 changeover to sludge application by soil penetration methods for 85% of total applications should substantially decrease odor problems associated with sludge application, though problems related to storage in holding basins would remain. It should be observed that rates and solids content of sludge applied during the early period of project development were much lower and storage time in the holding basins was much longer than planned so that the full odor potential may be understated by past complaints.

The only noise problems associated with the project stem from the booster pumping station at the dock in Liverpool and from sludge spraying units. Noise generated at the Liverpool barge dock increases the ambient noise level around the community of Liverpool. Tractors and sludge sprayers generate noise that is detected by sensitive receptors when they are in operation near the boundary of the project property. However, noise impacts are not severe; existing agricultural noise has similar effect.

b. Surface and groundwater pollution - Chemical and biological water quality data were collected from various monitoring stations on streams, reservoirs, and runoff retention basins. Pollutant concentrations violating Illinois water quality standards were recorded at both background and non-background stream quality monitoring stations with respect to sulfate, copper, iron, lead, manganese, and total dissolved solids. Fecal coliform concentrations also violated the Illinois standard, notably along Big Creek. Runoff over strip-mined areas and sludge application fields is most likely responsible for poor stream water quality. Sewage treatment plant and septic tank effluents, among other local pollution sources, also contribute. The established monitoring program is incapable of revealing these respective sources. Substandard water quality has also been documented for reservoirs at the project site. Reservoir water quality parameters registering below state standards include sulfate, copper, iron, lead, manganese, mercury, and total dissolved solids; these violations generally parallel those for stream waters.

The inadequate design and management of many runoff retention basins is indicated to be one of the major causes of surface water contamination. The operating permit issued by the Illinois EPA specifies retention basin effluent standards for total suspended solids (TSS), biological oxygen demand (BOD), and fecal coliform concentrations. Basin effluents that were below standards for TSS and BOD are known to have been discharged into receiving waterways. Even when standards are met by averaging the pollutant concentrations, peak concentrations ten times the specified averages occur for all three parameters. Short-term irreversible biotic effects such as a fish kill or decimation of benthos can result from such peak concentrations.

The runoff basins were (meant to be constructed) to provide a retention capacity for runoff from a 100-year storm. From the available data, it was determined that numerous retention basins could not contain 100-year storm runoff, and others could not contain even 25-year storm runoff. Runoff basins that are deficient in capacity are particularly ineffective in removing suspended solids, resulting in siltation and excess dissolved oxygen depletion in the receiving waterways and reservoirs. This is evidenced by the numerous violations of TSS and BOD standards for retention basin effluents. Also, reservoir violations of standards for total phosphorus and inorganic nitrogen and both stream and reservoir violations of the Illinois standard for total dissolved solids (TDS) point to the incapacity of retention basins for removing dissolved solids. These include nutrients from sludge which could contribute to the eutrophication of reservoirs and their receiving waterways, thus threatening aquatic life.

Groundwater samples taken from wells and springs in the project area have not clearly indicated any contamination resulting from sludge. Low rates of sludge application and low solids content of applied sludge during project development years, low soil permeability and biochemical soil filtering of sludge have favored the protection of well or spring water. However, a 1971 survey indicated contamination from natural geochemical sources, presumably by runoff and leachate from strip mined area. Since many of the heavy metal contaminants are found in both strip mine spoil and sewage sludge, ground water resources will be increasingly vulnerable to pollution by runoff and leaching as sludge loading rates are increased.

c. Soil contamination - Due to the paucity of data, impacts on soil quality resulting from the project cannot be defined rigorously, but can be surmised on the basis of general knowledge and studies of similar projects. The effects of sludge upon soil will vary with soil type, sludge properties, and application rates. The effects of sludge properties and application rates on a specific soil type must be studied under actual conditions, because the data required to accurately predict effects are inadequate.

In general, sludge has a beneficial effect upon the physical properties of soils. The high organic content of sludge provides a matrix for the formation of a stable soil structure. Increased aggregate stability results in increased infiltration and permeability rates, increased porosity, and decreased bulk density, all of which tend to reduce erosion potential, encourage good soil aeration, and favor aerobic over anaerobic soil conditions.

Although there is conflicting evidence, it is suspected that high concentrations of soluble salts in the sludge may affect soil chemistry and plant growth, possibly causing excessive plant uptake of toxic materials or trace metals. The trace elements in municipal wastes may occur largely in association with complex organic polyanions. This interaction between heavy metals and humic, polymeric substances in the sludge and soil may have a profound effect upon the mobility and toxicity of metal ions when sewage sludge is applied to agricultural soils.

Chemical analyses of soils at other sludge application sites have disclosed that accumulations of trace elements do occur and that most trace elements should be monitored, with particular emphasis placed upon cadmium, chromium, copper, lead, mercury, nickel, and zinc. Cadmium poses the greatest hazard, and both cadmium and copper appear in greater soil concentrations on project strip-mined lands than in place lands. Although data concerning organic compounds (such as pesticides) in the sludge and soils associated with the project are absent, other studies have shown that contamination from this source should not be excluded from the list of potential hazards. The Illinois Cooperative Extension Service has observed that other experiments also suggest that a long-term build-up of heavy metals should be the limiting factor in sludge loading rates, rather than the efficient utilization of nutrients which may prove a lesser limitation in the long run.

d. Direct health effects - Among all methods of sludge application, pressurized spraying offers the greatest potential for direct transfer of hazardous components to humans or animals. Inhalation of sludge aerosols possibly containing pathogens or toxic substances presents an opportunity for protracted and repetitive exposure and does not necessarily stimulate preventive action by those at risk. Assessing the risks associated with the inhalation of airborne particles is an extremely difficult task because of the absence of data concerning the nature and concentration of pathogens in the sludge, as sprayed, the virulence of these pathogens after downwind transport, and the number of inhaled organisms required for human and animal infection. Any evaluation of direct health hazards in Fulton County must therefore be a matter of judgment based on indirect evidence.

In any case, there is no doubt that the influent wastes at treatment plants contain a wide range of pathogens, including some viruses that are not totally destroyed by treatment and holding in the storage basins.

The most useful indirect information concerning the Fulton County project is the absence of reported ill effects.

Negative evidence of effects on health correlates with experience elsewhere, but may indicate only that the level of risk is low, rather than nonexistent. For instance, future high levels of pathogens or toxic substances in the sprayed sludge could result from a severe epidemic, changed industrial processes, defective treatment plant operation or abbreviated sludge holding time. In addition, this negative evidence is based on the absence of conspicuous ill effects rather than an active medical search for indicators.

A theoretical estimate of daily human respiratory intake of sludge particles, using a dispersion model and the meteorological conditions and sludge composition peculiar to the project, yields an intake of mercury well in excess of the World Health Organization (WHO) limit under worst weather conditions. The estimate assumed a sludge application rate of 2.25 dry tons per acre, and applied to distances of 250 to 1,150 meters from the source to the receptor. However, the WHO limits apply to continued daily intake. While sprayer operators at the site could sustain prolonged exposure, it is doubtful that such exposure could occur downwind beyond the site perimeter.

e. Indirect health effects - Indirect effects are caused by the consumption of plants or animals that have been contaminated by heavy metals. The interactions among sludge components and the food chain are complex and information concerning the ability of each trophic level to accumulate toxic compounds and pass them on to succeeding trophic levels is sparse and qualitative at best.

Separate studies have shown that trace elements available for plant uptake can accumulate in soils. Trace element uptake, particularly of cadmium and zinc, has been proven in corn and soybeans grown on sludge-treated land in Fulton County. Data on grasses, including wheat and rye, show a large variation in mineral uptake. What little data exist indicate that bioaccumulation of most trace elements does not occur in most types of livestock tissue. Bioaccumulation of elements such as cadmium is, however, known to occur in the kidney and liver of domestic animals. In addition, high concentration of sludge contents found in forage samples irrigated with sludge indicate that ingestion of forage may pose a significant problem to animals. Direct ingestion of dirt containing high levels of trace metals could present a significant hazard to low grazers such as sheep and to rooters such as swine.

Effects of sludge application on wild birds have not been investigated as far as can be determined. However, earthworms have been shown to accumulate heavy metals like cadmium, and adverse effects on birds that consume these worms are likely. An important consideration here is that the access of wild birds to sludge-treated lands cannot be controlled.

Evaluation of human health hazards resulting from ingestion of trace metals presents many problems. Susceptibility to specific mineral toxicities varies from individual to individual and so does the efficiency of digestion and absorption, which controls body loads of any component. The variety of foods that are normally consumed tends to dilute high levels of a particular food constituent. Another area of uncertainty is the possible localization of a dietary component in specific tissues or organs, which has the net effect of multiplying existing body loads. The most likely suspects for potential hazard are arsenic, cadmium, lead, mercury, and selenium. Both sludge and soil at the project site are high in cadmium, especially in relation to zinc. Cadmium enrichment may be the most limiting single factor in sludge loading rates.

The actual indirect hazard to humans would stem from the future use of reclaimed strip-mined land for cropping or livestock grazing, possibly resulting in consumption of accumulated trace elements. A family living in a rural or semi-rural atmosphere may derive food from their own garden or livestock, in which case a majority of their food intake might come directly or indirectly from reclaimed land. There would be no significant hazard to humans from future conservation and recreation uses of land such as hunting, fishing and prairie development.

E. MITIGATIVE AND PREVENTIVE MEASURES

Mitigative measures include those applicable to all potential problems, those that pertain to a few, and those that are specific to one problem. The most obvious and universal measure that can be taken to avoid adverse environmental effects is to improve the quality of the sewage sludge applied to the land. This section first addresses the quality of sludge associated with the project, as this is basic to any impact, and then discusses measures to prevent or ameliorate the adverse environmental effects noted in the previous section. It concludes by identifying data gaps and suggesting improvements in monitoring and research to increase the experimental value and decrease the risks of the Fulton County project.

1. Sludge Quality

It is evident that providing more advanced treatment at the MSDGC treatment plants to remove excess heavy metals would decrease hazards associated with salt enrichment of soils and human intake of heavy metals by aerosol inhalation and consumption of contaminated plant and animal produce. However, as this is presently very costly, advanced treatment or industrial pre-treatment will not be considered in this report.

To minimize the potential for adverse environmental effects resulting from the project, sludge quality standards are specified in the operating permit issued to the MSDGC. The quality of sludge from the Lawndale lagoons and from the West-Southwest (WSW) treatment plant was compared with applicable standards. As of May 1975, the sludge from the Lawndale lagoons had violated alkalinity standards 9.5% of the time. Sludge from the WSW plant had violated standards for total volatile solids 3.8% of the time, alkalinity standards 1.1% of the time, and pH standards 1.3% of the time.

Environmental effects from substandard sludge *per se* cannot be assessed because the sludge actually applied may have very different characteristics, depending on time in storage, mixing with supernatant, and so forth. However, any air pollution from sludge odors and aerosolization and contamination of surface water, groundwater, and soil from sludge application to land would be complicated and abetted by continued shipment of subgrade sludge. It is important to consider that any adverse environmental effects estimated from previous sludge applications may substantially understate their potential because the pollutant concentrations in sludge applied during the past developmental period have been atypically low. Also, average retention time in the holding basins has been much longer than planned.

A procedure should be implemented to ensure that only good quality sludge is shipped to Fulton County. If necessary, substandard sludge must be stored prior to shipment until its quality conforms with required standards. The capacity of the holding basins provides for a sufficiently long storage time, which should guarantee the destruction of pathogens in the sludge, but this does not alleviate the potential for odor problems, especially those associated with substandard sludge. Therefore, prolonged storage of sludge in the Lawndale lagoons prior to shipment to Fulton County is recommended as a mitigative measure. Because of icing at the lagoons during winter months, sludge consigned to Fulton County is drawn directly from the WSW digesters.

2. Mitigative Measures

Many of the environmental problems associated with the project could be avoided by eliminating spraying as an application method. Aerosolization from sludge spraying is a major source of odor, because volatilization from aerosols is extremely rapid. Spraying is also the main vehicle for direct adverse effects on human health caused by the inhalation of contaminated aerosols. Eliminating spraying would substantially reduce the amount of sludge coating on pasture grasses, and would therefore reduce the ingestion of sludge by grazing animals.

Steps are being taken by the MSDGC toward the goal of eliminating spraying, which is scheduled to account for only 15% of total applications in 1976. Until or unless spraying can be eliminated entirely, there are certain practices that will reduce potential impacts. Reducing spray pressure reduces sludge aerosolization, and reducing the height and inclination of the sprayer gun reduces the portion of sprayed sludge remaining airborne. In all cases, the sludge sprayer should be operated under conditions favoring dispersion and the viable decay of microorganisms: low windspeed, high turbulence, warm temperature, and bright daylight. Spraying should be avoided when the atmosphere is stable, air is cool, and the sky is overcast or dark.

Odor generation is a difficult problem, especially for odors originating from the sludge holding basins. White-capping at the surface of the basins due to high wind promotes sludge aerosolization, which is one of the major mechanisms for odor generation. The use of wind barriers such as tall, dense hedgerows or fences around the holding basins could reduce surface turbulence and wave action. The present requirement of a 4-foot freeboard from the sludge surface to the top of the berm provides baffling only for a short distance downwind. The use of floating wind baffles within the basins might prove an effective measure for controlling surface turbulence and, therefore, odor. Odor generation from the holding basins might also be reduced by the use of chemicals that suppress evaporation or mask malodorants. These two methods have not been proven economically or technically, but, if found to be effective without adverse environmental effects, could be used during unfavorable weather conditions when odor propagation is greatest.

Odors originating from sludge applied to the soil can be controlled by using methods of application that reduce the surface area of sludge exposed to the atmosphere. Soil incorporation by disking or, better yet, soil injection (see Figure I-2) is considered to be most effective in reducing odor potential because the top layer of soil acts as an odor blanket. In addition, sludge ponding in the application fields should be disallowed or certainly kept at a minimum. Ponding can be reduced by increasing the number of application runs and allowing one week to elapse between successive runs.

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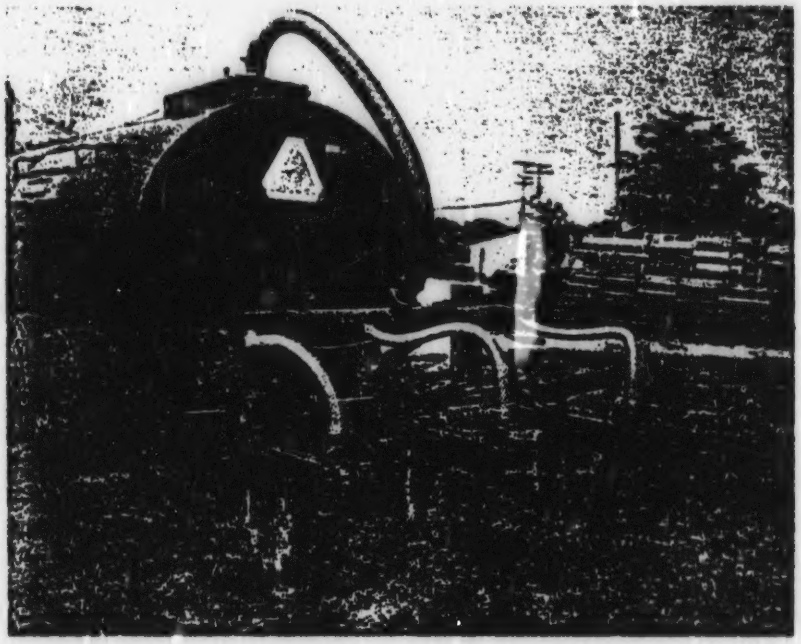

Figure I-2. Injection Unit Showing Three Injectors (MSDGC, 1975h)

To control surface water contamination, the effectiveness of runoff retention basins must be upgraded so that effluents meet required standards for total suspended solids and biological oxygen demand. Retarding runoff velocity and erosion by planting grass, sufficient recycling to the fields of substandard basin effluents, increasing the capacity of runoff basins, providing additional basins, or combinations of these measures are necessary to achieve required effluent quality.

One way to prevent adverse soil effects is by improving the quality of sludge before application. While the organic matter in sludge is highly beneficial to soil building on strip-mined land in the short run, the long-term soil adsorptivity of minerals and nutrients can become saturated, depending on availability to plants and their actual uptake. The results are groundwater pollution and reduced crop yields due to soil mineralization and leaching. Accumulation of toxic substances in the soil is significant in relation to possible uptake by plants and direct or subsequent ingestion by animals.

It is difficult to suggest explicit mitigative measures for regulating potential indirect health effects because this area is so vague. The only certain action that can be taken to avoid indirect human health effects is to prevent humans from consuming grain and vegetable crops, domestic livestock, and fish or wildlife raised on sludge-treated lands. This would, of course, inhibit future re-use of the land for cropping, grazing, hunting and fishing, which is inconsistent with some goals of land reclamation.

3. Monitoring and Research Programs

Implementation of the preventive and mitigative measures suggested above will certainly help to minimize adverse environmental effects. However, the general insufficiency of data makes the assessment or prediction of impacts uncertain and incomplete in most areas. Therefore, it is also recommended that a much more thorough evaluation of the actual hazards or risks be provided through an expanded program of monitoring and research.

An independent agency should collect, process, evaluate and publish all existing and future performance data pertaining to the project in cooperation with the Sanitary District, the Illinois EPA, the University of Illinois, and other interested parties. An improved research and monitoring program covering sludge, surface and groundwater, atmosphere, soils, crops and livestock, natural habitats, and fish and wildlife should be formulated and carried out. Relevant research findings would be available at least one year in advance of any major change in sludge processing, shipping, storage and spreading practices and allied agricultural and conservation practices.

Specifically, several sections of project land should be reserved for the evaluation of:

- Inorganic and organic constituents of strip-mined land prior to levelling, after levelling, after initial high sludge application rates, and on a yearly basis thereafter
- Effects of different application rates upon groundwater quality and plant uptake to identify upper limits of sustained soil holding capacity and crop yields
- Inorganic and organic sludge components found in crops and natural vegetation and in both wild and domestic animals introduced or raised on the project site
- Changes occurring when sludge application discontinues, such as decomposition of organic matter and leaching of heavy metals.

In addition, monitoring programs should be carefully implemented in the following areas:

- Biological and chemical analysis of sludge, including bacterial and viral loads, upon leaving the treatment plants and directly before sludge application
- Sampling of air downwind of remaining spraying operations to determine peak concentrations of pathogens, under conditions favoring a risk (low temperature, stable atmosphere, light wind, overcast day)
- Analysis of the nutrient and total dissolved solids (TDS) concentrations in effluents from runoff retention basins to determine nutrient and TDS inputs into receiving waterways and reservoirs where eutrophication may occur
- Identification of the contaminant source whenever high levels are noted in wells, streams and reservoirs, to ensure the effective performance of the control measures

- Approximation of groundwater flow pattern and velocity, using tracers introduced to upstream wells, as aid to pollution source identification

- Separate and periodic detection of available as well as total soil elements particularly in the root zone, and potentially toxic organics (such as pesticides) as well as trace elements

- Segregation of project and background effects to isolate natural and man-made pollution, especially heavy metals, biological oxygen demand and fecal coliforms, from geochemical sources, strip-mining activities and community waste disposal

- Analysis of public health records and data on industrial discharges, to provide a better understanding of the original inputs into the wastewater system.

As far as human health hazards from indirect causes are concerned, future land use of strip-mined areas reclaimed by sludge application should be regulated. The listing below summarizes the best, worst, and average circumstances associated with human health hazards as a function of future land use:

Worst Case

- Sale of land to farm operators who live on the premises and raise their own food with no monitoring or controls.

- Rural housing development where residents garden with no monitoring controls.

Best Case

- Land remains in hands of the MSDGC with rental to farmers, providing management and monitoring controls.

- Land developed for outdoor recreation, prairie preservation, and tree farms.

Average Case

- Land remains in hands of the MSDGC until hazards are defined; crop or pasture land is rented to farmers with management control.

- Land remains in hands of the MSDGC until hazards are defined; crop or pasture land is rented to farmers without management control, but all produce is sampled and tested prior to release.
- Development of confined livestock operations for beef cattle or swine; produce is sampled and tested prior to release.
- Land is developed as fish and wildlife preserve with hunting and fishing allowed after establishing zero hazard level; management and monitoring controls are provided.

In spite of its potential environmental hazards, the Fulton County project has already produced tangible benefits associated with sludge application to land. Levelling and removal of rock from strip-mined land to prepare for sludge application have increased the suitability of the site for mechanized agriculture and for recreational use. Drainage control systems developed with the application fields have increased land suitability for livestock feedlots and intensive crop production requiring high rates of fertilizer and pesticide application. Undoubtedly, the addition of sludge has beneficially affected the physical properties of project soils. The application of sludge to strip-mined land will increase the mineral nutrients in soils and help to condition the soil for more intensive uses. In the prairie area these minerals should help to support a greater diversity of plant life. An obvious benefit of the project has been the creation of jobs for approximately 120 skilled and unskilled contract laborers.

The Fulton County project could serve as a research area for assessing the benefits and drawbacks of applying sewage sludge to strip-mined land. The project, if carefully and thoroughly monitored and evaluated as an experimental large-scale prototype of strip mine land reclamation, could help immensely to ensure environmentally sound recycling instead of burning and burying wastewater solids. Convertion of waste to fertilizer and waste land to fertile land is basic to future environmental policy and deserves more consideration.

II. BACKGROUND AND INTRODUCTION

After briefly discussing the general aspects of sludge disposal on land, this chapter presents a concise overview of the Fulton County project itself. Its political and legal aspects, such as policy issues and current litigation, and its physical development goals are summarized. The socio-economic and environmental basis for the geographic planning area of the project is examined. The applicable operating permits and standards are reviewed. Also included are descriptions of interacting programs for sludge utilization such as the Big Bluestem Program. The wastewater treatment and sludge disposal systems that are presently operated by the Metropolitan Sanitary District of Greater Chicago (MSDGC) are highlighted.

A. PROJECT BACKGROUND AND OVERVIEW

This section is divided into three parts. The first is a general discussion of the utilization of sewage sludge on agricultural land. Included are descriptions of sewage sludge characteristics, sludge application rates and methods, crop response to sludge, and the benefits and possible problems associated with this method of sludge disposal. The second part traces the history of the Fulton County Prairie Plan program and addresses the meaning of the goal of "reclamation". The third part discusses three associated programs, two dealing with actual sludge utilization and a third providing inter-agency and community liaison in executing the Prairie Plan.

1. Sewage Sludge on Agricultural Land

Sewage sludge is frequently a surplus commodity of municipalities and has in some cases accumulated in amounts large enough to pose severe problems of storage and disposal. Environmental and economic constraints limit disposal methods. However, if applied to soil at a rate equivalent to modern irrigation,digested sewage sludge will supply many plant nutrients in the amounts needed for a growing crop and will also improve soil properties. Utilization on agricultural land therefore appears to be an attractive solution from the standpoint of cost to the municipality for disposal as well as cost of nutrients and organic matter needed to renovate and fertilize depleted or barren land. Benefits and problems associated with the use of sewage sludge on agricultural land are discussed in this section.

a. Characteristics of Sewage Sludge - The term "sludge", as applied to this study, refers to anaerobically digested sewage sludge, a stablized material with an earthy odor. Liquid sewage sludge is brown-to-blackish in color and contains dissolved, colloidal, and suspended solids. Its characteristics depend to a great extent on the source of the original waste, especially the types of industries contributing wastewater, the treatment provided and the handling of sludge and a variety of other factors.

Liquid sewage sludge may vary from less than 1% solids to more than 10%, but most sludges contain 2 to 5% solids as they finish the treatment process. The solid portion is composed of approximately equal amounts of inorganic and organic materials. The inorganic portion is largely fine particles having the texture of silt and clay, and contains mainly nitrogen, phosphorous, sulfur, chlorine, carbonates, and metal salts. The organic portion is a complex mixture of constituents comprising organic carbon, nitrogen, phosphorous, and sulfur.

Table II-1 gives a range of the chemical composition of sludge and specifications for a "typical" liquid, digested sewage sludge as it flows from the digester. The composition of different batches of sludge can vary appreciably from the values shown; these are given only as a general guideline. Not all of the nitrogen in sewage sludge is available to crops during the year of application. Some may be lost by volatilization or leaching, and the remaining organic nitrogen must be mineralized before it can be assimilated by crops. Also, nearly all of the

Table II-1. Composition of Fresh, Anaerobically Digested Sewage Sludge (Illinois Cooperative Extension Service, 1975)

Element	Concentration range	Typical sludge (dry basis) Concentration	Typical sludge (dry basis) Amount
	percent	*percent*	*pounds/ton*
Elements essential for plants			
Nitrogen-organic	2 to 5	3	60
Nitrogen ammonium	1 to 3	2	40
(Nitrogen-total)	(1 to 6)	(5)	(100)
Phosphorus-as P	.8 to 6	3	60
(Phosphorus as P_2O_5)		(6.8)	(137)
Potassium-as K	.1 to .7	.4	8
(Potassium as K_2O)		(.5)	(10)
Calcium	1 to 8	3	60
Magnesium	5 to 2	1	20
Sulfur	.3 to 1.5	.9	18
Iron	.1 to 5	4	80
	ppm	*ppm*	
Sodium	800 to 4,000	2,000	4
Zinc	50 to 50,000	5,000	10
Copper	200 to 17,000	1,000	2
Manganese	100 to 800	500	1
Boron	15 to 1,000	100	.2
Elements not essential for plants			
Cadmium	3 to 3,000	150	.3
Lead	100 to 10,000	1,000	2
Mercury	1 to 100	3	Trace
Chromium	50 to 30,000	3,000	6
Nickel	25 to 8,000	400	0.8

NOTE: Values vary according to source, treatment, and other factors. Sludges held in storage lagoons for long periods may be considerably lower in nitrogen content.

minor and trace elements can be toxic at some concentration; their availability to plants depends on soil properties, crop varieties, and many other factors.

b. Application Methods and Rates - Handling the large volume of water required to convey the sludge nutrients needed by a growing crop imposes some restrictions on the methods used for applying liquid sludge. A sludge containing solids of 6% or less can be handled as a liquid, pumped through pipes, and carried in tank trucks, railroad tank cars, and barges. Although there are limitations on the type of pump used, sludge can generally be handled by the equipment used for spreading liquid manure. Sludge with more than 10% solids may require special equipment to deal with high viscosity. Dewatered sludge may be handled as solid manure.

Liquid sludge can be sprayed through large-diameter irrigation nozzles. It can be spread in furrows through gated irrigation pipe. In spite of the high water content of liquid sludge, it is not a satisfactory substitute source for irrigation water because even a minimal rate of irrigation would supply nutrients and salts at levels potentially toxic to crops.

Liquid sludge can be spread on the soil by tank trucks. The hauling distance is obviously limited by the large weight of the water that is handled. In some present operations in Illinois, sludge is pumped through a flexible hose to an injection plow travelling through the field. At the plow, sludge flows through a manifold which connects with outlets at each plowshare or disc. Sludge can thus be incorporated immediately into the soil. It is necessary that caution be exercised in applying sludge to sloping land to insure that runoff water does not contaminate streams and other bodies of water.

> Application rates are specified in terms of inches of liquid (as for rain or irrigation water), tons of liquid per acre, or tons of dry solids per acre. A layer of liquid sludge 1 inch deep amounts to about 27,000 gallons (100 tons) on each acre covered. If the sludge has 3 percent solids, 3 tons of dry solids will be added to each acre by each 1-inch application. At 5 percent nitrogen and 3 percent phosphorus, this sludge will supply 300 pounds of total nitrogen and 180 pounds of phosphorus per acre. If the sludge had 5 percent solids, the 1-inch layer over an acre would still weigh about 100 tons, but would contain 5 tons of dry solids and furnish 500 pounds of total nitrogen and 300 pounds of total phosphorus per acre. (Illinois Cooperative Extension Service, 1975)

In determining the correct application rate to satisfy crop requirements for nutrients, many variables must be taken into consideration. For example, the percentages of specific nutrient concentrations that are in a form available for plant uptake, the loss of elements from leaching through the soil, and the mineralization or immobilization of elements after application must be determined. An application rate that is suitable for one constituent of sludge might be unsuitable for another, causing either nutrient deficiency or toxicity. In addition, the contribution of trace elements, especially heavy metals, may limit the long-range disposal of sludge on agricultural lands.

Sewage sludge is particularly well adapted for use on strip mined lands where the topsoil has not been replaced. Most of the soils there are high in potassium but low in nitrogen, phosphorous, some micronutrients, and organic matter; sewage sludge is an excellent source for these components. With sludge application, there is the option of going directly into row crop production after the levelling of strip mine spoil banks. There is a lower likelihood of phosphorous toxicity from heavy application rates since these soils are so low in phosphorous.

Application rates must be specified according to the analysis of the sludge being used, and sufficient sampling must be done to measure variability in composition over a reasonable period of time.

c. Crop Response - The University of Illinois has conducted research concerning crop responses to liquid, anaerobically digested sewage sludge since 1967. When sludge was spread in furrows between rows of corn, it was found that corn yields generally increased in direct proportion to the amount of sludge applied. The corn was grown on poorly drained soil low in organic matter. The organic matter in the surface soil was increased in proportion to the quantity of sludge applied the preceding year.

Soybean responses to sludge were evaluated in the same manner, and yields were found to generally increase with the amount of sludge applied. The only problems to develop in the course of the experiment were symptoms of phosphorous toxicity and excess soluble salt in the plants receiving the greatest application of sludge. However, when the excess salts were leached out by rainfall, the problem of phosphorous toxicity was alleviated.

A field experiment was set up on the University of Illinois Vegetable Research Farm in Mason County in 1974 to compare sludge, manure, and an inorganic fertilizer as nutrient sources for corn. Only two replications were performed and only one year's data are available, but the results for sludge use are encouraging. Yields of corn as high as 157 bushels per acre were obtained from 2 inches of sludge applied in furrows between the rows after planting. Similar yields were obtained from conventional fertilizer application techniques.

> While crops grown on sandy soils might benefit most from the use of an organic fertilizer source such as sewage sludge, we do not yet have enough experience with sludge on these soils to know whether additional problems may result. These soils have low base exchange capacities; and, consequently, may have a low capability for holding metal ions. Hence, toxicity problems could occur much sooner from repeated applications. Also, nitrogen leaching may occur to a greater extent with a resultant increase in pollution hazards. These things are being studied. (Illinois Cooperative Extension Service, 1975)

d. Added Benefits and Possible Problems - Sludge provides a source of organic matter that may be beneficial in many soils, particularly those low in organic matter, such as sandy soils or previously strip-mined lands. Organic matter is beneficial in holding plant nutrients in the soil complex and in facilitating their slow release. Improved structure and water-holding characteristics result from an increase in soil organic matter when it is at a low level (under 3%).

The application of sludge to agricultural lands also poses some problems. Odors from sludge can create problems under certain circumstances. Persons living adjacent to areas where sludge is applied to land or stored in basins may frequently complain of objectionable odors. If the sewage sludge has not been thoroughly processed, the resulting odors may be very noticeable. In addition, when sludge is held in lagoons, the upper layers of liquid become high in ammonia and some is lost to the atmosphere. The MSDGC has returned to Chicago much of the supernatant liquid from their holding basins to alleviate this problem. Odor problems can be partially alleviated by minimizing the surface area and the retention time of the sludge in holding basins, and by injecting the liquid sludge into the soil rather than spraying it on the surface.

According to the Illinois Cooperative Extension Service, sludge high in soluble salts, if applied in large amounts, can retard seed germination and plant growth and adversely affect soil structure. However, sludge generally has a low ratio of sodium to calcium and magnesium, indicating a low absorption of sodium. The sodium that is absorbed by soils tends to be leached out in humid areas where there is an annual net movement of water down through the soil profile. There seems to be little cause for concern about soluble salts in Illinois, providing that sludge is applied at agronomic rates (not exceeding the utilization of nutrients by crops).

Many of the concerns about long-term sludge application have centered around the trace metals in sludge. The elements of most concern are zinc, copper, nickel, and cadmium; but such concern extends to mercury, lead, boron, chromium, cobalt, selenium, and molybdenum. The fear is that repeated applications of sludge might build up concentrations of these elements in the soil to levels toxic to crops; also that metals absorbed by plants could enter the food chain at undesirable levels. In addition, these elements remain bound in the soil, and any problems they create are difficult to correct. The University of Illinois has sponsored research in an attempt to follow the transfer of trace elements into the food chain, and studies made so far provide little evidence to warrant concern about detrimental trace-metal accumulations in soils or plants where municipal sludges are applied at agronomic rates.

There has been serious concern that sewage sludge might contain pathogens and that animal and human health problems might result from sludge utilization. However, University of Illinois studies have shown that viruses are unlikely to survive a period of 15 days in a heated anaerobic digester, at least in a condition capable of causing an infection. Much the same situation was found for several kinds of parasites.

In regard to nitrogen, it was found that both the rate of nitrogen transformation to nitrate and the movement through soil are the same, regardless of the source. Phosphorous poses somewhat more of a problem, in that phosphorus added to soils as a sludge constituent appears to be highly available to crops. Hence, it is possible for available phosphorus to accumulate in soils to toxic levels for sensitive crops if sludge application rates are high. Also, the levels of phosphorus in drainage water may possibly increase to the point of posing a eutrophication threat when drainage water is returned to non-flowing surface waters. However, these problems are not expected to result as long as agronomic rates of sludge application are not exceeded.

2. Project History and Issues

This section presents a summary of the events leading to the Fulton County project (the Prairie Plan) and the rationale behind the executive decisions that were made. A definition of "reclamation" as the goal of the project is discussed, and there is a brief summary of the environmental litigation resulting from the project. Also, the related activities of several allied programs are described.

a. History and Policy Matters - Fulton County citizens have been concerned about the effects of strip mining in the County for many years. The first collective action was taken in 1970, when the County Board of Supervisors and the State's Attorney's Office formed a special citizens committee. This group discussed the pending strip mine landfill proposal in Livingston County and Stark County, and directed the State's Attorney to investigate the feasibility of such a project in Fulton County.

It was apparent from studies of the landfill project that, although it would effectively level the mined area, some measures would have to be taken to modify the inorganic mine spoil material covering the landfill. It was then that the use of digested sewage sludge for soil rehabilitation was proposed. Subsequently, the County Planning Administrator and the County Board members investigated the sludge project underway in Arcola to determine whether Fulton County should consider such a process. As a result of this and further investigations, the Mines and Mining Committee proposed to the County Board a resolution to negotiate for such a project, which was approved 30-0.

The MSDGC made a presentation to Fulton County officials on September 11, 1970, and on September 15, the Mining Committee, at the Sanitary District's invitation, toured the District's facilities in Chicago. The Mines and Mining Committee undertook a series of discussions with various mining companies and the MSDGC attempting to organize a reclamation project in the County. These meetings lasted until the beginning of November 1970 without obtaining a commitment from any mining company. The objective of the discussions was a lease arrangement between Fulton County and the mining companies and then a lease-back arrangement between Fulton County and the Sanitary District which would place direct control of the land with Fulton County. However, before any such contract could be developed, a private landowner negotiated and sold his large holdings directly to the District.

The Fulton County Board was presented with an approach to strip mine reclamation capitalizing on the ability of the Chicago region to pay for solutions to its problems of growth. Presumably, there was no State or Federal aid for large scale reclamation available to the County. Fulton County had in excess of 45,000 acres of strip-mined ground and was adding to this at a rate of 1,200 to 2,000 acres per year. The reclamation proposed by the MSDGC would be accomplished at no cost to the County. According to MSDGC (1975a), it was between six and ten times cheaper to dispose of sewage sludge on strip-mined land than within the boundaries of a metropolitan area. Presumably, a project utilizing waste products from an urban area would be tightly controlled by both State and Federal agencies having the necessary expertise and authority to ensure the environmental safety of Fulton County. In addition, direct involvement of County government in the project from its conception would offer strong local controls. Based on this reasoning, the County Board chose to support the Sanitary District proposal.

b. Reclamation and Re-Use - By its strictest definition, land reclamation would require that all conditions existing prior to mining operations be restored. These would include topography, surface and subsurface soils and drainage, water quality, vegetation, wildlife, land use and population. However, as it is quite evident that this would be nearly impossible to achieve, reclamation cannot be defined in this way.

A practical approach would be to establish three parameters by which to measure reclamation: surface topography, surface soils and land use. Perhaps the most important aspect of reclamation is restoring the use of the land. Although near-original contours may be achieved and soil building on stripped ground is successful, a failure to re-establish an economic use of the land would prevent full reclamation. Too often a "reclaimed" acreage, originally in some productive use, goes virtually unused.

Every attempt should be made to insure that reclaimed strip mine lands are capable of supporting the uses most in demand and that will serve the most beneficial purpose.

c. Environmental Litigation - As of December 12, 1975, a number of legal actions have been filed both by the Metropolitan Sanitary District of Greater Chicago and against the Sanitary District. In Ripper v. MSD and County of Fulton, various local residents have sought injunctive relief against the District's Fulton County operations and damages for alleged odor nuisance. As of the end of the year, the action was at the discovery stage, the District's motion to dismiss having been denied.

IEPA v. MSD (Mr. Parkhurst) is an enforcement case of the Illinois EPA before the Pollution Control Board, charging air pollution violations against the District's Fulton County Program during 1974. The case was held in discovery, with the assertion of attorney-client privilege concerning withheld documents delaying the conclusion. The agency has recently turned over the withheld documents, and the hearing officer has set a pre-hearing for early January 1976.

The Sanitary District filed the case MSD v. IEPA as a permit appeal on March 27, 1975. However, at the District's request, any hearing or determination on the part of the Pollution Control Board has been stayed, pending disposition of the above case, IEPA v. MSD.

In another case of MSD v. IEPA, a mandamus action was brought by the District to compel the issuance of its 1975 Fulton County comprehensive operating permit. A hearing was set for October 28, 1975, on the question of whether the agency can withhold documents from discovery on the assertion of attorney-client privilege. The case is now set for a status report on March 11, 1976.

In yet another case of MSD v. IEPA, there is an appeal by the District from certain conditions imposed in its Gale and United Electric permits issued by the IEPA. Hearings of October 29, 30, and 31 were set in Lewistown, Illinois. The Fulton County citizen's group intervened in the action. A 90-day limit for disposition of the case afforded the Pollution Control Board until November 27, 1975, to render a decision on the appeal, but the District has further extended the time for decision to January 30, 1976.

3. Interacting Programs

The use of sludge for the reclamation of agricultural land is only one of many purposes of sludge disposal. This section will discuss two allied programs dealing with sludge disposal. The Nu-Earth Program is one in which the Sanitary District distributes cost-free the air-dried solids from Imhoff sludge digestion. The Big Bluestem Program, whose objective is to recreate a native prairie on sludge-reclaimed land, is embryonic in its development. This section will conclude with an identification of the Fulton County Steering Committee's role in the implementation of the MSDGC's Prairie Plan.

a. Nu-Earth Program - The Nu-Earth Program can be traced back to February 1974 when the Chicago Tribune featured the benefits of organic fertilizer, presenting a detailed map of the Lawndale Avenue air-dried Imhoff solids pick-up site. By September 1974, requests for Nu-Earth had outstripped the District's capacity to load and deliver.

The process yielding Nu-Earth begins when wastewater, after primary treatment, is pumped to an Imhoff tank where sedimentation, thickening and stabilization of the sludge occurs. The sludge is then placed in open-air drying beds at the treatment plant. The partially dried sludge, now containing solids of approximately 25%, is transported to the Harlem Storage Site where it is dewatered and partially composted. Now called "Nu-Earth" having a solids content of 60%, the sludge is transported via railroad,car or truck to various pick-up sites. There Nu-Earth is available free of charge to gardeners, highway departments, farmers, and others.

Nu-Earth distributed in 1974 amounted to 97,366 cubic yards. During the first 11 months of 1975, approximately 198,000 cubic yards have been distributed, far exceeding the goal of 130,000 cubic yards for the entire year. The distribution program has been effective in producing a net reduction in volume of Nu-Earth in storage at the Harlem Avenue Storage Site. This is extremely beneficial, as it provides a useful outlet for the vast amounts of sludge that accumulate from wastewater treatment at the individual plants. Permission has been obtained from the IEPA to deliver Nu-Earth outside the MSDGC jurisdiction without requiring permits. Because the program is new, emphasis is mainly on increasing public utilization, and potential adverse environmental effects have not been examined extensively. Monitoring of environmental effects from widespread distribution is far from feasible.

Possible adverse effects include seepage of the soluble constituents into groundwater, and surface runoff into streams. Both of these mechanisms present a risk of ground and surface water contamination by organic and toxic components of the sludge. In addition, application to crops for animal and human consumption provides a possible pathway for biomagnification of toxic elements such as heavy metals in the food chain.

b. Big Bluestem Program - The idea for the Big Bluestem Prairie was proposed to the MSDGC in July 1973 as a solution to the problems and environmental restrictions encountered in reclaiming strip-mined land in Fulton County by recycling sewage sludge. The principle is that a tallgrass prairie may prove even better than crops and pasture in recycling and reclamation. The prairie project would restore to the state something of its original heritage, and prairie plants offer new possibilities for both agriculture and land reclamation.

The objective of the Big Bluestem Prairie project is to recreate a native Illinois prairie, complete with its wildlife, on strip-mined land by recycling the byproducts of sewage treatment. Once established, the wildlife populations would be allowed to strike their own dynamic balance with each other, and their prairie environment, as would the plant life. The area of the Big Bluestem Prairie is envisioned as essentially the 3,000-acre Gale Farm on the Cuba-Canton road (Figure IV-13, page IV-60) virtually all of which has been strip mined. Approximately 1,700 acres have less than a 5% grade, and sewage sludge will be recycled on about 1,000 of these acres.

Wildlife is the key to the tourist potential of Big Bluestem and is vital to the prairie ecology itself. Big Bluestem would be a prime genetic reservoir of native wildlife for re-stocking other areas of the country. Buffalo and elk would dominate from a tourist and ecological standpoint, but all of the animals native to the Illinois prairie except the bear, wolf, and cougar or mountain lion, would be included. Non-native animal species which would enhance tourist appeal may be kept on display. Introduction of animals could begin at the onset of the project. There are governmental and private non-profit agencies interested in establishing various species, and the large herbivores could be introduced by the MSDGC. To date, 9 buffalo and 2 elk have been acquired for the project.

A minimum herd size of 300 buffalo, 150 elk, and 125 deer is projected. Populations of other animals would be allowed to fluctuate naturally. Interpretive nature programs, both guided and self-guided, will be needed, along with viewing accommodations such as trails, blinds, and riding tours.

c. Prairie Plan (Fulton County Steering Committee) - The Fulton County land reclamation program is locally known as the Prairie Plan. The Fulton County Steering Committee was established in 1971 to provide public participation in the Prairie Plan. The committee is comprised of public officials, private citizens, and MSDGC staff personnel. The members of the Steering Committee are:

- The Metropolitan Sanitary District of Greater Chicago (Sponsor and Chairman)
- Fulton County Board (Co-Sponsor)
- State of Illinois Department of Business and Economic Development
- State of Illinois Department of Conservation
- State of Illinois Environmental Protection Agency
- Western Illinois Regional Council
- University of Illinois
- Fulton County Health Department
- Fulton County Planning Commission
- City of Canton
- City of Cuba
- City of Lewistown
- Soil Conservation Service

B. PLANNING AREA AND STANDARDS

This section will describe the geographic areas that were chosen for consideration of effects of the Fulton County project, and the rationale behind that choice. As different geographic areas will be influenced socio-economically and environmentally, these are discussed separately. The section continues with a description of the pollution control standards that must be complied with by the Metropolitan Sanitary District of Greater Chicago in the operation of the Fulton County project.

1. Basis for the Planning Area

The study of socio-economic and land use impacts employs three areas of focus. The largest area of study is regional, covering Fulton County and any influences of Peoria. A more refined area contains land surrounding the project area and includes Canton. The smallest area of study is confined within the boundaries of the project site (see Figure II-1).

The selection of the geographic focus of the study of each socio-economic or land use variable depends on two factors. One is the size of the geographic units for which the associated data are reported. For example, some census data dealing with population are available at a township level of disagregation, while data in the Census of Agriculture are available in greatest detail at a county scale. The other determining factor is the type of information to be studied. For example, soils data are inherently more site-specific than are data concerning, say, trends in manufacturing employment.

The study of environmental effects of the project includes odor and noise nuisance, potential contamination of surface and ground water and soil, possible health effects of airborne pathogens, and potential biomagnification of toxic materials in food chains via crop and livestock production and consumption. Study topics are diversified so that

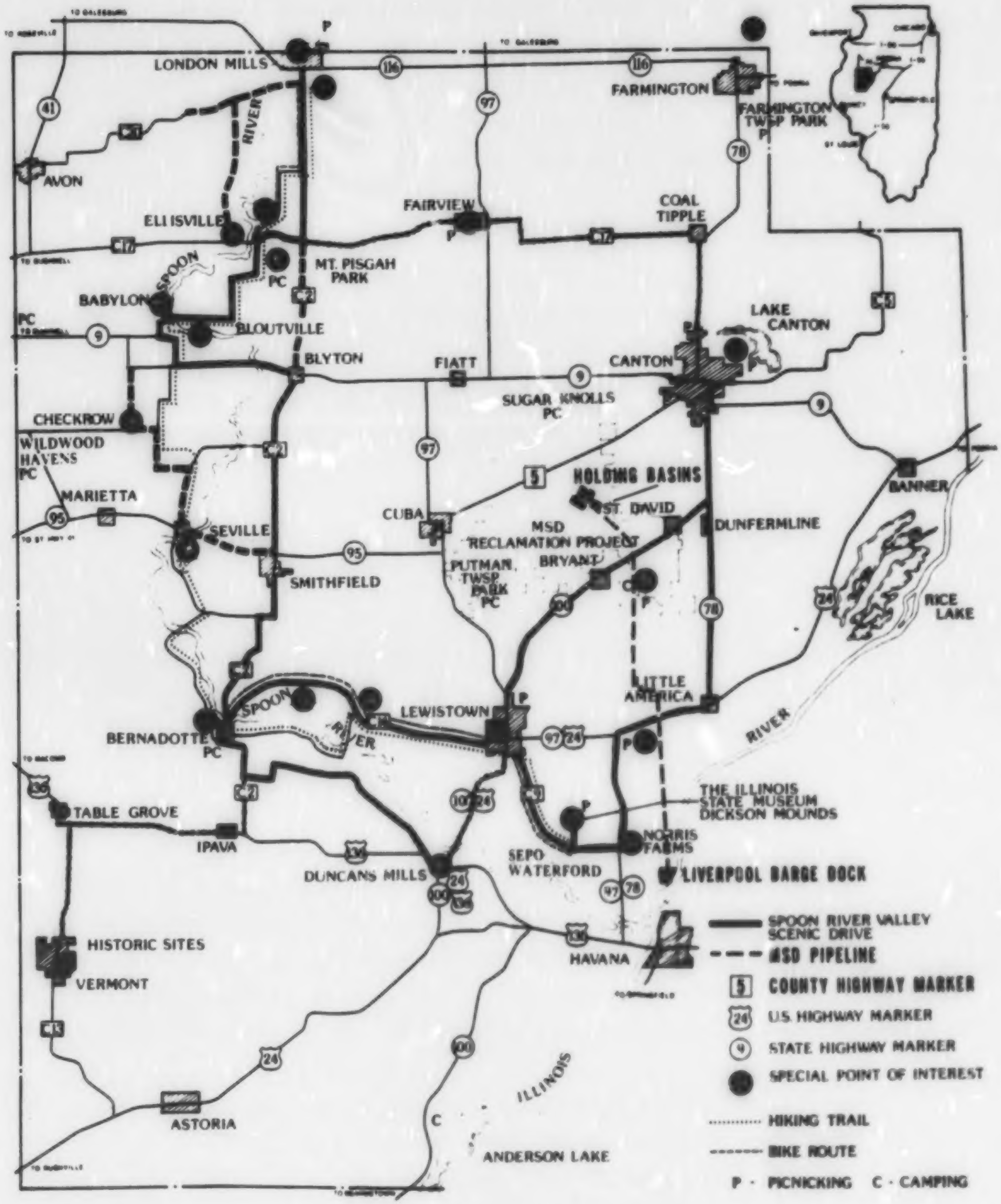
LONDON MILLS
FARMINGTON
FARMINGTON TWSP PARK
AVON
RIVER
ELLISVILLE
FAIRVIEW
COAL TIPPLE
MT. PISGAH PARK
SPOON
BABYLON
BLOUTVILLE
LAKE CANTON
BLYTON
FIATT
CANTON
SUGAR KNOLLS PC
CHECKROW
WILDWOOD HAVENS PC
MARIETTA
HOLDING BASINS
ST. DAVID
BANNER
CUBA
DUNFERMLINE
SEVILLE
MSD RECLAMATION PROJECT
BRYANT
SMITHFIELD
PUTMAN TWSP PARK PC
RICE LAKE
LITTLE AMERICA
LEWISTOWN
BERNADOTTE PC
RIVER
TABLE GROVE
IPAVA
THE ILLINOIS STATE MUSEUM DICKSON MOUNDS
NORRIS FARMS
SEPO
WATERFORD
DUNCANS MILLS
LIVERPOOL BARGE DOCK
HISTORIC SITES
VERMONT
HAVANA
ASTORIA
ILLINOIS
ANDERSON LAKE
SPOON RIVER VALLEY SCENIC DRIVE
MSD PIPELINE
COUNTY HIGHWAY MARKER
U.S. HIGHWAY MARKER
STATE HIGHWAY MARKER
SPECIAL POINT OF INTEREST
HIKING TRAIL
BIKE ROUTE
P - PICNICKING C - CAMPING

Figure II-1. Project Site and surrounding area.

no definite geographic boundary can be assigned to accommodate all effects. For example, problems associated with odors and airborne pathogens, which can travel great distances depending upon meteorological conditions, require a larger study area. Related climatological features must be examined not only locally but also regionally. Therefore, flexibility of boundaries for study of environmental effects is required according to individual study topics.

Generally speaking, the study area is extended to at least 5 miles from the boundaries of the project property. This area includes communities of Canton, Cuba, St. David, Bryant, and Lewistown (see Figure II-1, page II-17). All environmental and health effects resulting from the project are evaluated against the applicable standards as discussed in Section II.B.2. and confirmed with findings from similar studies in the literature.

2. Pollution Control Standards

The MSDGC must comply with three sets of regulations in order to construct and operate the Fulton County land reclamation project. There are effluent standards, as stated in the Illinois EPA Water Pollution Control Permit, which reflect the water pollution regulations of Illinois Rule 404, governing the concentrations of total dissolved solids, BOD, and fecal coliforms. The Sanitary District must construct, operate and maintain the project so as to maintain the General Water Quality Standards for the State of Illinois. In addition, the Fulton County Board of Health requires a permit for any sewage sludge operation; it contains standards for the chemical composition, transportation, storage, use and disposal of digested and undigested sewage sludge. These separate sets of standards are examined in turn in this section.

a. Water Quality Standards - The water quality standards for the State of Illinois are designed to protect Illinois waters for aquatic life, agricultural and industrial uses, and primary and secondary contact (for recreation), and to ensure the aesthetic quality of the aquatic environment. Except during periods when flows are less than the average minimum 7-day low flow, which occurs once in 10 years, all waters of the State must meet the standards defined in Table II-2. In addition, the following standards must be met:

- Any substance toxic to aquatic life shall not exceed 1/10 of the 48-hour median tolerance limit (48-hour TL_m) for native fish or essential fish food organisms
- All State waters must be free from unnatural sludge or bottom deposits, floating debris, visible oil, odor, unnatural plant or algal growth, unnatural color or turbidity, or matter in concentrations or combinations toxic or harmful to human, animal, plant, or aquatic life of other than natural origin
- There shall be no artificially induced temperature changes that may adversely affect aquatic life, that may disturb the normal daily and seasonal temperature fluctuations, or that may cause the temperature to rise more than 5°F above natural temperature.

b. Effluent Standards - To construct and/or operate any water pollution control facility in the State of Illinois, a permit from the Illinois Environmental Protection Agency is required. Each permit is comprised of standard conditions common to all such permits and a number of special conditions peculiar to a specific case. The Comprehensive Operating Permit issued to the MSDGC contains 15 Special Conditions. (The permit is presented in its entirety in Appendix A).

According to Special Condition #9, the effluent discharged from any runoff retention basin must meet the applicable effluent requirements for discharge to the waters of the State as established by the Illinois Pollution Control Board Rules and Regulations. The point of discharge is considered to be the overflow structure of each of the retention basins.

Table II-2. Water Quality Standards for the State of Illinois

Parameter	Standard (mg/l)
Ammonia nitrogen (as N)	1.5
Arsenic	1.0
Barium	5.0
Boron	1.0
Cadmium	0.05
Chloride	500.
Chromium (total hexavalent)	0.05
Chromium (total trivalent)	1.0
Copper	0.02
Cyanide	0.025
Dissolved Oxygen	
Minimum for 16 out of 24 hours	6.0
Minimum at any time	5.0
Fluoride	1.4
Iron	1.0
Lead	0.1
Manganese	1.0
Mercury	0.0005
Nickel	1.0
Phenols	0.1
Phosphorous (as P)*	0.05
Selenium	1.0
Silver	0.005
Sulfate	500.
Total Dissolved Solids	1000.
Zinc	1.0
	pH
Acidity-alkalinity	6.5-9.0
	per 100 ml
Fecal coliforms**	
Geometric mean	200
Maximum for 10% of samples	400
	pCi/l***
Radioactivity	
Beta	100
Radium 226	1
Strontium 90	2

---

*In any reservoir or lake, or in any stream at the point of entry to any reservoir or lake

**Based on a minimum of five samples taken over not more than a 30-day period

***Pico curies per liter

Special Condition #10 states that certain contaminant concentrations are to be considered background values, and that the effluent standards are met when the sum of the background concentration and the allowable regulatory concentration is greater than the measured concentration for the respective parameter. The numerical values of these standards are presented in Table II-3 below.

Table II-3. Effluent Standards for Retention Basin Discharge in the State of Illinois

	Total Suspended Solids (mg/l)	BOD (mg/l)	Fecal Coliform (mg/l)
Background Arithmetic Mean	61.7	2.75	--
Background Geometric Mean	--	--	94.3
Water Pollution Regulations of Illinois Rule 404 (Regulatory Concentration)	5.0	4.0	400.0
Effluent Standard (Total concentration)	66.7	6.75	494.3

c. Sludge Standards - The Fulton County Board of Health Sewage Sludge Rules and Regulations require that any transportation, storage, use, or disposal of sewage sludge or digested sewage sludge requires a valid permit from the Board of Health. All sewage sludge transported for storage or applied to land must be digested, and all digested sludge placed in a storage basin must meet the following standards:

- Volatile acids - no more than five 24-hour composite samples taken in a 30-day period shall exceed 300 mg/l
- Alkalinity - no more than 5% of the 24-hour composite samples taken in a 30-day period shall be lower than 2,500 mg/l
- Volatile solids - no 24-hour composite sample shall be more than 62% of total solids
- pH - no 24-hour composite sample shall be less than 6.9 units.

These tests must be performed by the permit holder on a 24-hour composite sample of digested sewage sludge to be transported for storage in Fulton County. Weekly results are to be submitted to the Fulton County Board of Health, which retains the right to independently sample the sewage sludge of any permit holder in Fulton County.

The use and disposal of digested sewage sludge must also comply with the following standards:

- Cropping practices shall be such that soil loss does not exceed tolerable limits as defined by the Universal Soil Loss Equation for that soil type
- Digested sewage sludge shall be incorporated into bare soils and absorbed into all soils
- Underground aquifers shall not be contaminated with digested sewage sludge or its constituents
- Spray applications shall be done so as to contain the material within the land-application area designated in the permit.

In addition, digested sewage sludge shall not be applied:

- Within 100 feet of a stream, lake, well, or any potable water supply
- Within 200 feet of a dwelling unit
- On root crops for human consumption
- In a flood plain, unless adequate pollution control mechanisms are available
- To frozen or snow-covered land
- Outside of the land-application area.

C. PRESENT WASTEWATER TREATMENT SYSTEMS

As the Fulton County reclamation project utilizes sludge generated by the operations of the Metropolitan Sanitary District of Greater Chicago, any discussion of the project would be incomplete without first describing the associated wastewater treatment systems. This section discusses in detail the existing MSDGC systems for wastewater treatment and sludge processing and disposal, with emphasis upon the particular plants contributing sludge for land disposal in Fulton County. The section concludes with a forecast of future sludge production.

1. MSDGC Sewage Treatment Plants

The MSDGC has six wastewater treatment plants, the locations of which are shown in Figure II-2. The West-Southwest, Calumet and Northside plants are secondary treatment works, while Hanover, Streamwood, and Lemont provide tertiary treatment. The John E. Egan Water Reclamation Plant is presently under construction, and the Streamwood Plant is scheduled to be retired upon completion of the Poplar Creek Interception System.

The capacities and average 1973 flow ranges of each plant are presented in Table II-4. The present water-borne waste distributions from major industries discharging 10,000 gallons per day or more are 135 MGD to the West-Southwest Plant, 22 MGD to Northside, and 38 MGD to Calumet. The performance of these plants in terms of 5-day biological oxygen demand (BOD_5), total suspended solids (TSS) and ammonia (NH_3-N) is reported in both effluent concentration and percent reduction in Table II-4.

At the present time, only the West-Southwest and Northside facilities produce sludge to be shipped to Fulton County for land reclamation (MSDGC, 1975 a,b,c). These two, therefore, receive detailed attention concerning their treatment processes and sludge handling and disposal facilities. The Northside facility has no sludge stabilization recycling or disposal systems. After concentration, sludge at approximately 1.5% solids is pumped to the West-Southwest facility via pipeline.

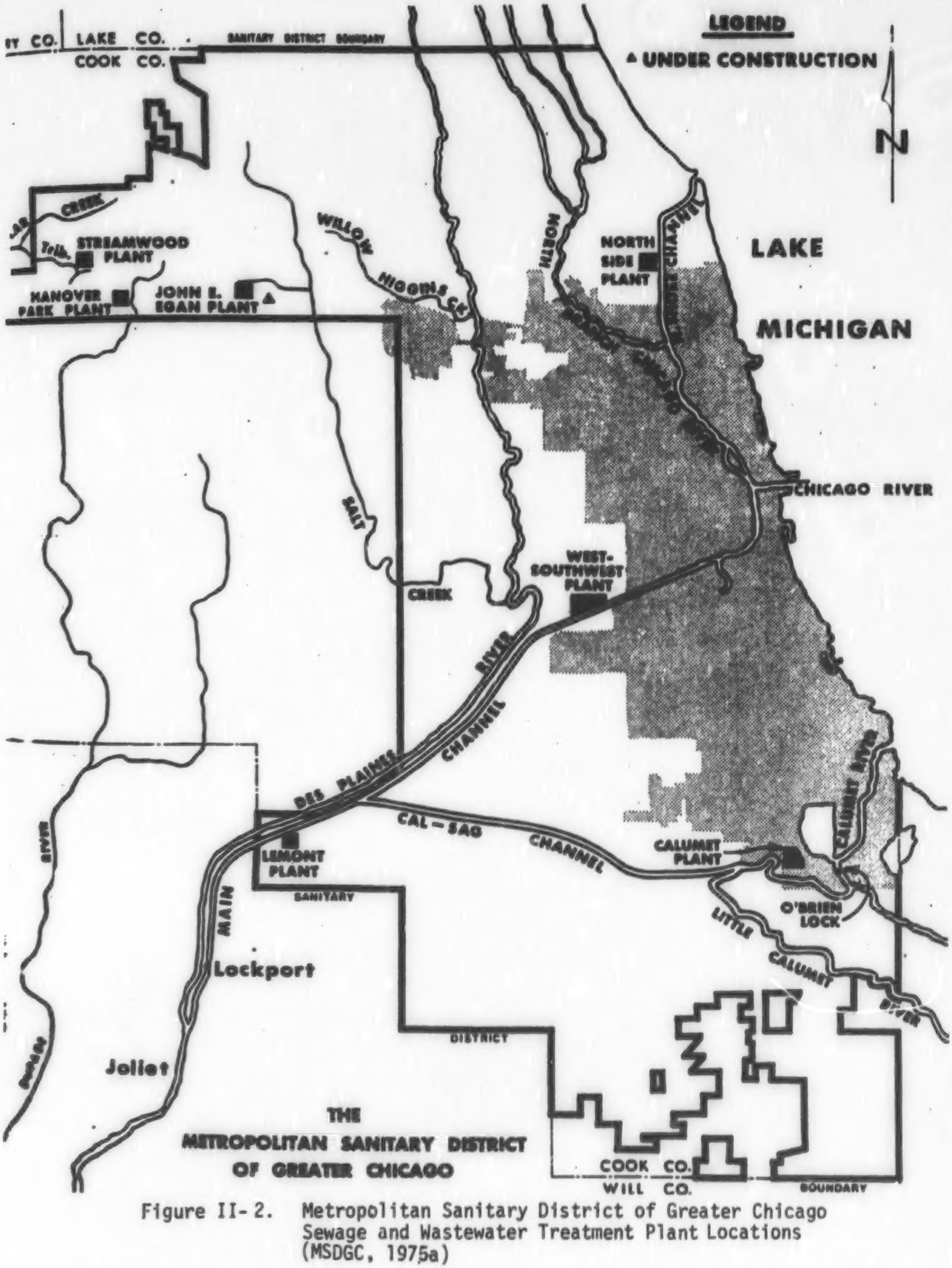
LEGEND
▲ UNDER CONSTRUCTION
N
LAKE CO.
COOK CO.
SANITARY DISTRICT BOUNDARY
CREEK
Trib.
STREAMWOOD PLANT
HANOVER PARK PLANT
JOHN E. EGAN PLANT
WILLOW HIGGINS CK.
NORTH
NORTH SIDE PLANT
CHANNEL
LAKE MICHIGAN
CHICAGO RIVER
SALT CREEK
WEST-SOUTHWEST PLANT
DES PLAINES RIVER
CHANNEL
CAL-SAG CHANNEL
LEMONT PLANT
CALUMET PLANT
CALUMET RIVER
O'BRIEN LOCK
LITTLE CALUMET RIVER
SANITARY DISTRICT
MAIN
Lockport
Joliet
RIVER
DUPAGE
THE METROPOLITAN SANITARY DISTRICT OF GREATER CHICAGO
COOK CO.
WILL CO.
BOUNDARY

Figure II-2. Metropolitan Sanitary District of Greater Chicago Sewage and Wastewater Treatment Plant Locations (MSDGC, 1975a)

Table II-4. Performance of MSDGC Plants (MSDGC, 1975a)

	West-Southwest	Northside	Calumet	Hanover	Lemont	Streamwood
Degree of Treatment	Secondary	Secondary	Secondary	Tertiary	Tertiary	Tertiary
Capacity (MGD)	1200	333	219	6.0	1.2	3.0
Flow Ranges in 1973 (MGD)						
Average Daily	886.0	343.8	209.5	5.6	0.9	2.4
Lowest Daily	621.0	259.1	148.0	2.6	0.3	1.3
Highest Daily	1416.0	406.6	315.8	14.3	2.2	5.7
Average Effluent Concentrations (ppm) and Percent Reduction in 1973						
BOD_5	7 (96%)	10 (90%)	5 (90%)	3 (96%)	2 (98%)	24 (80%)
TSS	9 (96%)	13 (88%)	12 (95%)	5 (97%)	3 (97%)	33 (78%)
NH_3	7	5	18	1	0.2	12

In 1973, the Northside plant pumped 2.2 MGD (132 dt/d) of primary and secondary sludge to the West-Southwest plant (MSDGC , 1975c).

2. West-Southwest Treatment Plant

The WSW plant is comprised of the West Side Treatment Works, which is an Imhoff facility, and the Southwest Side Treatment Works, an activated sludge facility. Figure II-3 shows the layout of the existing facilities. Figure II-4 is a simplified flow diagram depicting the processes of both the West Side and Southwest Side Works. The facilities of both treatment works can be divided conveniently into two groups: sewage treatment systems; sludge processing systems. The sewage treatment systems are briefly discussed below, followed by a detailed description of the sludge processing systems.

The West Side Treatment Works consist of a grit chamber and screen house, skimming tanks, Imhoff tanks for sewage treatment and sludge stabilization, and drying beds for sludge dewatering. There are 108 Imhoff tanks arranged in three batteries of 36 tanks each. Digested Imhoff sludge is dried on 12 underdrained sand beds 80 feet wide and 800 to 1,400 feet long, with a total area of 25.1 acres. Air-dried sludge is scraped from the beds and hauled to a dump 3 miles west of the plant. Dried Imhoff sludge is given away as "Nu-Earth". As an option, Imhoff sludge may be screened prior to either lagooning or heated anaerobic digestion.

The Southwest Treatment Works include aerated grit chambers, grit dewatering building, preliminary settling tanks, aeration tanks for the activated sludge process, and final settling tanks for sewage treatment. Heat drying, heated anaerobic digestion, and wet air oxidation (or the Zimpro process) are the three sludge processes used at the Southwest Treatment Works. These are discussed, separately, below.

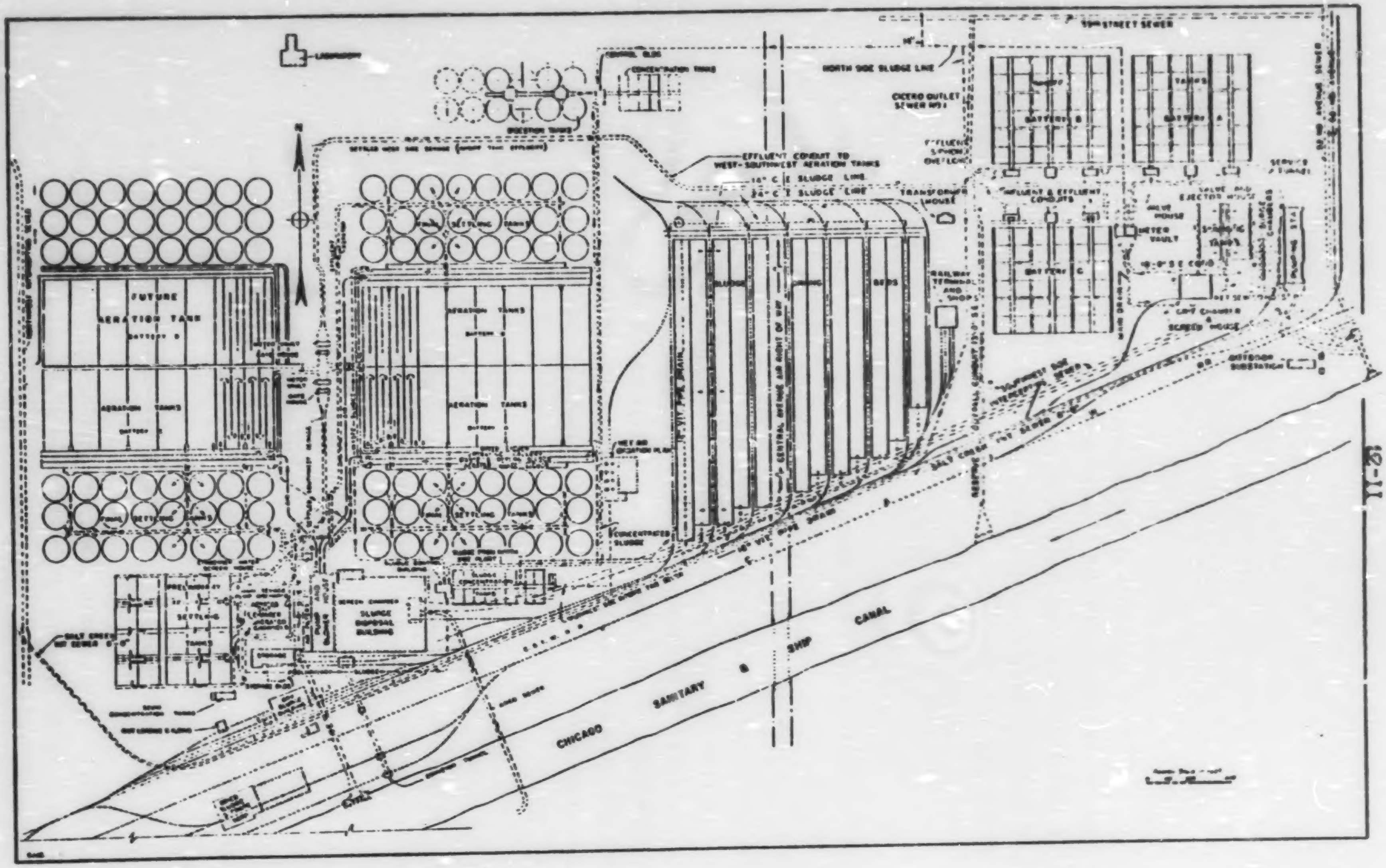
FUTURE
AERATION TANKS
BATTERY D
AERATION TANKS
FINAL SETTLING TANKS
DIGESTION TANKS
CONCENTRATION TANKS
NORTH SIDE SLUDGE LINE
CICERO OUTLET
SEWER NO. 1
EFFLUENT CONDUIT TO
WEST-SOUTHWEST AERATION TANKS
SLUDGE LINE
TRANSFORMER HOUSE
CENTRAL AVENUE AIR RIGHT OF WAY
SLUDGE
DRYING
BEDS
RAILWAY TERMINAL AND SHOP
BATTERY A
BATTERY B
BATTERY C
TANKS
INFLUENT & EFFLUENT CONDUITS
VALVE AND EJECTOR HOUSE
METER VAULT
GRIT CHAMBER
SCREEN HOUSE
PUMPING STA
SERVICE TUNNEL
MAIN DRAIN
SOUTHWEST SIDE INTERCEPTING SEWER
CONCENTRATED SLUDGE
SLUDGE DISPOSAL BUILDING
SCREEN CHAMBER
PUMP AND BLOWER HOUSE
PRELIMINARY SETTLING TANKS
SALT CREEK INT SEWER
CHICAGO
SANITARY
&
SHIP
CANAL
N

Figure II-3. West-Southwest Sewage Treatment Works Plant Layout (MSDGC, 1975a)

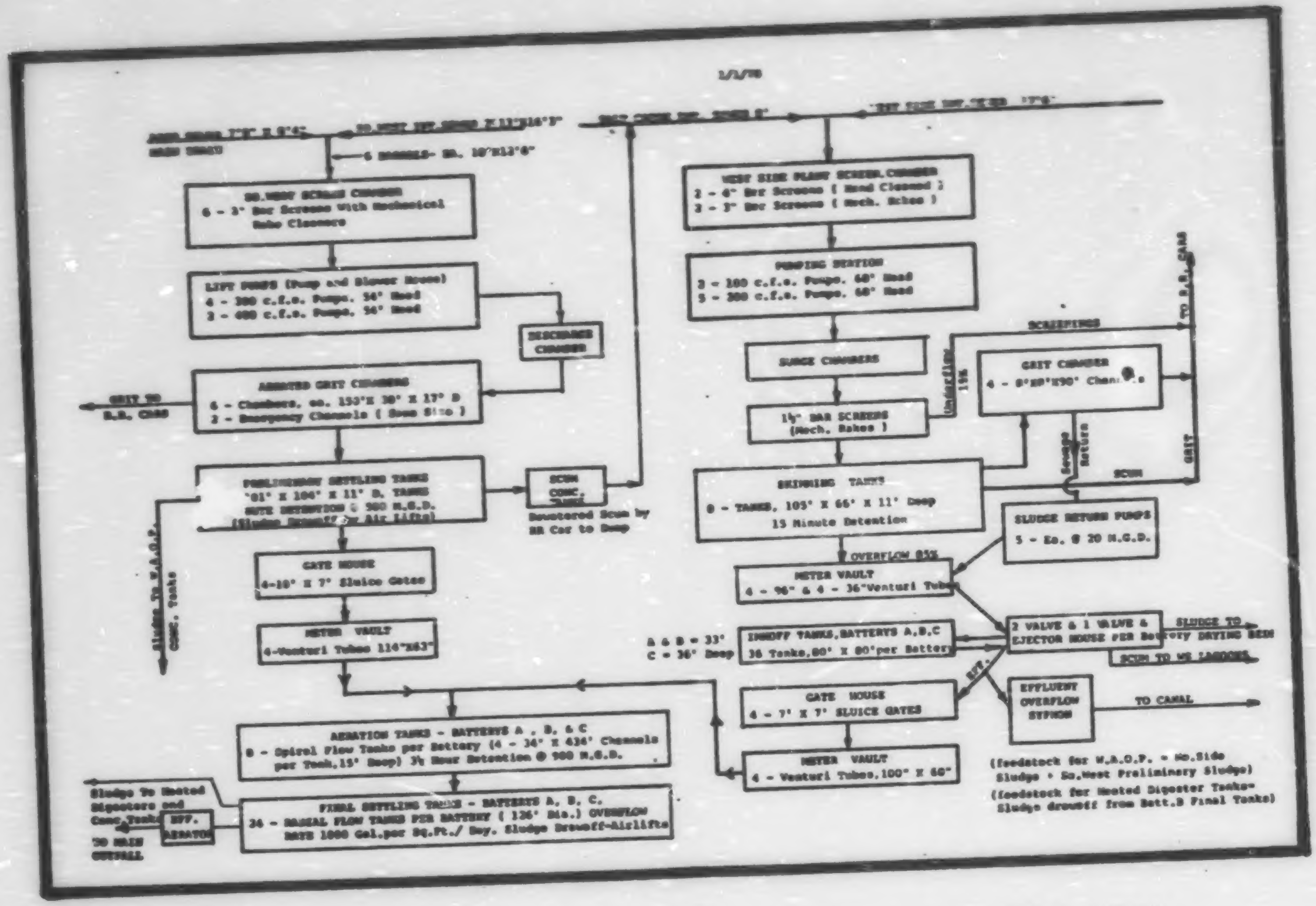
1/1/78
6 BARRELS- Ea. 10'X12'6"
SO.WEST SCREEN CHAMBER
6 - 3" Bar Screens With Mechanical Rake Cleaners
LIFT PUMPS (Pump and Blower House)
4 - 300 c.f.s. Pumps, 54' Head
2 - 600 c.f.s. Pumps, 54' Head
DISCHARGE CHAMBER
AERATED GRIT CHAMBERS
6 - Chambers, ea. 153'X 30' X 17' D
2 - Emergency Channels (Same Size)
GRIT TO R.R. CARS
PRELIMINARY SETTLING TANKS
81' X 106' X 11' D. TANKS
MINUTE DETENTION @ 900 M.G.D.
(Sludge Drawoff by Air Lifts)
SCUM CONC. TANKS
Dewatered Scum by RR Car to Dump
Sludge To W.A.O.P. CONC. Tanks
GATE HOUSE
4-10' X 7' Sluice Gates
METER VAULT
4-Venturi Tubes 114"X63"
AERATION TANKS - BATTERYS A , B, & C
8 - Spiral Flow Tanks per Battery (4 - 34' X 434' Channels per Tank,15' Deep) 3½ Hour Detention @ 900 M.G.D.
FINAL SETTLING TANKS - BATTERYS A, B, C.
24 - RADIAL FLOW TANKS PER BATTERY (126' Dia.) OVERFLOW RATE 1000 Gal.per Sq.Ft./ Day. Sludge Drawoff-Airlifts
Sludge To Heated Digesters and Conc.Tanks
EFF. AERATOR
TO MAIN OUTFALL
WEST SIDE PLANT SCREEN.CHAMBER
2 - 4" Bar Screens (Hand Cleaned)
3 - 3" Bar Screens (Mech. Rakes)
PUMPING STATION
3 - 100 c.f.s. Pumps, 68' Head
5 - 200 c.f.s. Pumps, 68' Head
SURGE CHAMBERS
1½" BAR SCREENS (Mech. Rakes)
Underflow 15%
SCREENINGS
TO R.R. CARS
GRIT CHAMBER
4 - 8'X8'X90' Channels
Sewage Return
GRIT
SCUM
SKIMMING TANKS
8 - TANKS, 105' X 66' X 11' Deep
15 Minute Detention
SLUDGE RETURN PUMPS
5 - Ea. @ 20 M.G.D.
OVERFLOW 85%
METER VAULT
4 - 96" & 4 - 36"Venturi Tubes
2 VALVE & 1 VALVE & EJECTOR HOUSE PER Battery
SLUDGE TO DRYING BEDS
SCUM TO WS LAGOONS
IMHOFF TANKS,BATTERYS A,B,C
36 Tanks,80' X 80'per Battery
A & B = 33'
C = 36' Deep
EFF.
GATE HOUSE
4 - 7' X 7' SLUICE GATES
METER VAULT
4 - Venturi Tubes,100" X 60"
EFFLUENT OVERFLOW SYPHON
TO CANAL
(feedstock for W.A.O.P. = No.Side Sludge + So.West Preliminary Sludge)
(feedstock for Heated Digester Tanks= Sludge drawoff from Batt.B Final Tanks)

Figure II-4. West-Southwest Sewage Treatment Works Flow Diagram (MSDGC, 1975a)

The heat drying process includes screening of sludge by bar screens and grinding the screenings by hammer mills, sludge dewatering by 98 vacuum filters, and sludge drying by multi-hearth flash dryers. The dried sludge produced is sold as fertilizer base material.

In the heated anaerobic digestion process, some sludge,after screening and grinding, is concentrated in either flotation-sedimentation tanks or simple sedimentation tanks. Concentrated sludge is pumped to anaerobic digesters; a total of 12 digesters are in operation. The sludge is then circulated through heaters and returned to the anaerobic digester, where mixing is accomplished by digester gas recirculation. Digested sludge is then pumped to holding tanks and lagoons.

The wet air oxidation process oxidizes sludge organic matter under high pressure and elevated temperature. The method is based on the principle of wet combustion for degrading sludge organic matter. Sludge is ground and then pumped to four 40,000-gallon storage tanks, each of which supplies a reactor. The total capacity of the four units is approximately 300 tons. The sludge, which usually contains between 2 1/2 to 4 1/2% solids, is pumped from the storage tanks, pressurized, and mixed with air at 1,800 psi before entering the wet air reactor-. The sludge-air mixture usually attains a temperature of 400°F or higher. Oxidation in the reactors results in a temperature rise of 100°F. The effluent is then pumped to lagoons west of the plant. This process has been on standby since July 1972 (MSDGC, 1975a).

3. Sludge Processing and Disposal

In 1973, the MSDGC produced approximately 1,250 dry tons per day (dt/d) of sewage sludge. The MSDGC has a number of systems available for sludge handling, stabilization and disposal, and is developing others. (These are presented in Figure II-5.) Detailed discussions on the systems related to this study are given in sections V.A through V.F. The sludge processing systems at the WSW plant are summarized in Table II-5, which gives the types of systems utilized in 1973 and their capacities in dry tons per day.

SYSTEMS	GENERATING	STABILIZATION	CONCENTRATION	DISPOSAL RECYCLE
PRIMARY	■			
SECONDARY	■			
TERTIARY	■			
IMHOFF	■	■	■	
HEAT DRY		■	■	
VACUUM FILTRATION			■	
AIR DRY			■	
SETTLING AND FLOTATION-CONC			■	
DIGESTION		■		
WET AIR OXIDATION		■		
LAGOONING		■	■	■
STOCKPILING		■	■	■
NU-EARTH				■
SELL HEAT-DRIED				■
LAGOON CLEANING CONTRACTS				■
CALUMET AND HANOVER FARMS				■
FULTON COUNTY:				■
SOIL INCORPORATION				■
SOIL INJECTION				■
CROP SPRAY				■
FOREST SPRAY				■
OVERLAND FLOW				■

Figure II-5. Available MSDGC Solids Systems (MSDGC)

Table II-5. West-Southwest Sludge Processing Systems, 1973 (MSDGC, 1975a)

System	Type	Capacity (dt/d)
Imhoff Digestion, Air Drying on Sand Beds, and Storage	Stabilization and Recycling	100
Heat Drying	Stabilization and Recycling	380
Heated Anaerobic Digestion	Stabilization	300
Wet Air Oxidation Process (on standby basis only)	Stabilization	190
Land Reclamation (as of December 1974)	Recycling	90
Lagoons (requiring periodic cleaning; no long-term disposal capacity available)	Disposal	0

Typical in-plant sludge flow and sludge operations at the West-Southwest plant in 1973 are presented in Figure II- 6. Approximately 713 dt/d of sludge solids entered the plant, 33 dt/d of which were discharged with the plant effluent into a sanitary receiving canal. The remaining 680 dt/d entered one of four sludge handling, stabilization, and disposal schemes:

- Heat drying and fertilizer sale
- Heated anaerobic digestion and lagooning
- Heated anaerobic digestion and land application in Fulton County
- Imhoff digestion followed by air drying on sand beds and subsequent distribution as "Nu-Earth".

Approximately 172 dt/d of the 680 dt/d solids were eventually recycled back to the head end of the plant in several forms: supernatants derived from concentration units, heat dryers, Lawndale lagoons, and sludge holding basins at the land application site in Fulton County; underdrainage from Imhoff air-drying beds; and filtrate from vacuum filters.

The heat drying units generated approximately 200 dt/d of solids, digestion and lagooning accounted for 38 dt/d, and digestion and land application in Fulton County totaled about 209 dt/d. The sludge from the Imhoff tanks was split into three portions, each receiving different treatment. Approximately 11.7 dt/d of raw Imhoff sludge joined the digester sludge for lagooning. About 20.4 dt/d were shipped to Fulton County for land application. Approximately 94.5 dt/d were air-dried on sand beds and transported, along with approximately 100 dt/d of scum and grit generated by the plant, to the Harlem Avenue Dump where the air-dried solids were given away as "Nu-Earth". During sludge processing, approximately 85.5 dt/d of material were released as particulates and gases to the atmosphere from the stacks of the heat dryers, and approximately 63.4 dt/d were released to the atmosphere by the heated anaerobic digesters due to volatilization and gasification of sludge.

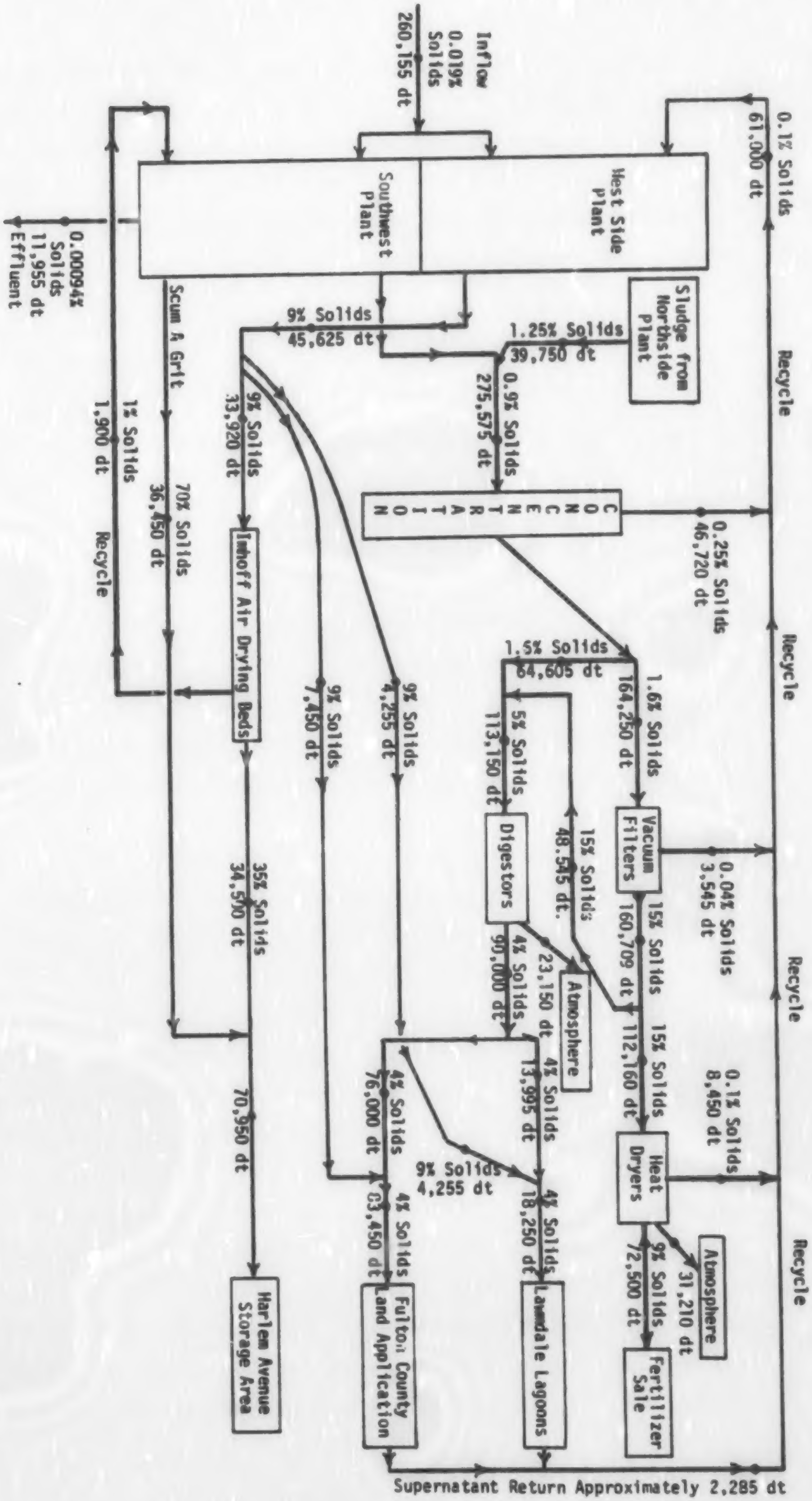
Inflow
0.019% Solids
260,155 dt
West Side Plant
Southwest Plant
0.1% Solids
61,000 dt
Recycle
Sludge from Northside Plant
1.25% Solids
39,750 dt
9% Solids
45,625 dt
0.9% Solids
275,575 dt
CONCENTRATION
0.25% Solids
46,720 dt
Recycle
1.5% Solids
64,605 dt
1.6% Solids
164,250 dt
Vacuum Filters
0.04% Solids
3,545 dt
15% Solids
160,709 dt
15% Solids
48,545 dt
5% Solids
113,150 dt
Digestors
23,150 dt
Atmosphere
4% Solids
90,000 dt
15% Solids
112,160 dt
Recycle
Heat Dryers
0.1% Solids
8,450 dt
Atmosphere
31,210 dt
9% Solids
72,500 dt
Fertilizer Sale
Recycle
4% Solids
13,995 dt
4% Solids
18,250 dt
Lawndale Lagoons
9% Solids
4,255 dt
9% Solids
4,255 dt
9% Solids
7,450 dt
4% Solids
76,000 dt
4% Solids
103,450 dt
Fulton County Land Application
Supernatant Return Approximately 2,285 dt
9% Solids
33,920 dt
Imhoff Air Drying Beds
35% Solids
34,570 dt
70,950 dt
Harlem Avenue Storage Area
Scum & Grit
70% Solids
36,450 dt
1% Solids
1,900 dt
Recycle
0.0009% Solids
11,955 dt
Effluent

Figure II-6. In-Plant Sludge Flow and Sludge Operation at West-Southwest Plant, 1973 (MSDGC, 1975b)

The average sludge production rates for different sludge processing systems in the WSW plant are summarized in Table II-7. Future sewage flows and sludge generation rates are important in comparing future treatment and disposal alternatives. Based on area population forecasts, the MSDGC has derived the future average dry weather flow and raw sludge production, presented in Table II-6 below.

Table II-6. Forecast of Average Dry Weather Flow (ADWF) and Raw Sludge Production

	Northside Plant		WSW Plant	
Year	ADWF (MGD)	Raw Sludge (dt/d)	ADWF (MGD)	Raw Sludge (dt/d)
1973*	324	--	838	641
1980	279	39	882	878
1990	292	46	895	1121
2000	304	52	910	1138

*Actual production as a base for comparison

Table II-7. Average Sludge Production Rates for Different Sludge Processing Systems in the WSW Plant, 1973 (MSDGC, 1975b)

Sludge Processing System	Average Annual Sludge Production (dry tons/day)	
Fertilizer Sale		
• Sludge Concentration + Vacuum Filtration + Heat Drying + Fertilizer Sale		200.0
Lagooning		
• Sludge Concentration + Anaerobic Digestion + Lagooning	38.3	50.0
• Imhoff Digestion + Lagooning	11.7	
Land Application		
• Imhoff Digestion + Land Application	20.4	228.6
• Sludge Concentration + Anaerobic Digestion + Land Application	208.2	
Land Disposal		
• Imhoff Digestion + Air Drying + Land Disposal	94.5	194.5
• Scum and Grit Removal + Land Disposal	100.0	

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Illinois Cooperative Extension Service, Utilization of Sewage Sludge on Agricultural Land (SM-29), April 1975.

MSDGC, Facilities Planning Study, MSDGC Overview Report, Planning Department, Revised January 1975a.

MSDGC, Facilities Planning Study, Central Facility Area, Planning Department, Revised January 1975b.

MSDGC, Facilities Planning Study, Northside Facility Area, Planning Department, Revised January 1975c.

III. DESCRIPTION OF THE PROJECT

This chapter presents an in-depth description of the project. The first section describes the project site and operations, including processes of sludge shipment, storage, and application. The second section discusses the environmental control and monitoring systems that were incorporated into the project to protect the environmental quality of the site and its surroundings. The control and monitoring systems discussed include those pertaining to sludge, water, soil, biota, and air.

A. PROJECT SITE AND OPERATIONS

This section introduces the project site and surrounding area in terms of location, land use, and terrain. The three basic elements of a sludge disposal system for land reclamation are sludge shipment, storage, and land application. These project operations are reviewed, along with a profile of sludge characteristics, in the second part of this section. A third part describes the rates and techniques of sludge application.

1. Sludge Application Site

The land reclamation project of the MSDGC is located centrally in Fulton County, Illinois. The project site is immediately east of the village of Cuba or approximately 25 miles west-southwest of Peoria. Most of the site is sandwiched between the Cuba-Canton Road (Illinois Route 5) and Illinois Route 100 near Canton to the northeast and Lewistown to the south. Big Creek flows southwesterly through the project site and merges with Spoon River, which is a tributary of the Illinois River, a major navigable waterway. (A regional map prepared from a 1:250,000 USGS map, showing the project site and surroundings, is presented in Figure II-1, page II-17).

The surroundings of the project are rural. Some growth of population is expected, but the area is not in the path of urban or suburban growth. The major local economic influences are farming, strip mining, and manufacturing. Canton and Lewistown are the principal nearby central places. Peoria and Pekin have a major regional influence on the project area; providing easily accessable centers of trade employment and recreation. Land use in the area surrounding the project site is predominantly unintensive. The primary uses are row crop, farming, livestock grazing and strip mining. Farming and mining are becoming highly mechanized, employing progressively fewer people.

More than 60% of the project site was strip-mined for coal years ago, forming a rough terrain of depressions and lakes without drainage outlets. Soils have a high clay content and are relatively impervious. However, some paths of rapid flow developed by rearrangement and re-distribution of soils and unconsolidated bedrock during mining operations. Access roads generally form the dividing ridge lines between adjacent mini-sections.

Since 1971, the project site has been contoured and terraced to create fields suitable for sludge application and retention basins have been constructed to contain stormwater runoff. Four large holding basins have been constructed for the purpose of storing sludge prior to field application. A detailed description of the project features, operations, and environmental control and monitoring systems is presented in the following section.

2. Sludge Shipment and Storage

Digested sludge from the West-Southwest plant or sludge from the Lawndale lagoons, or a mixture of both, is barged approximately 200 miles down the Illinois River to the dock at Liverpool in Fulton County (Figure III-1). The barges have a capacity of 1,500 to 2,500 tons and must pass a series of river locks during the journey. The sludge is unloaded using 6,000 gpm-capacity pumps and relayed by booster pumps of 6,600 gpm capacity to the four sludge holding basins about 10.5 miles inland (Figure III-2A & III-2B)

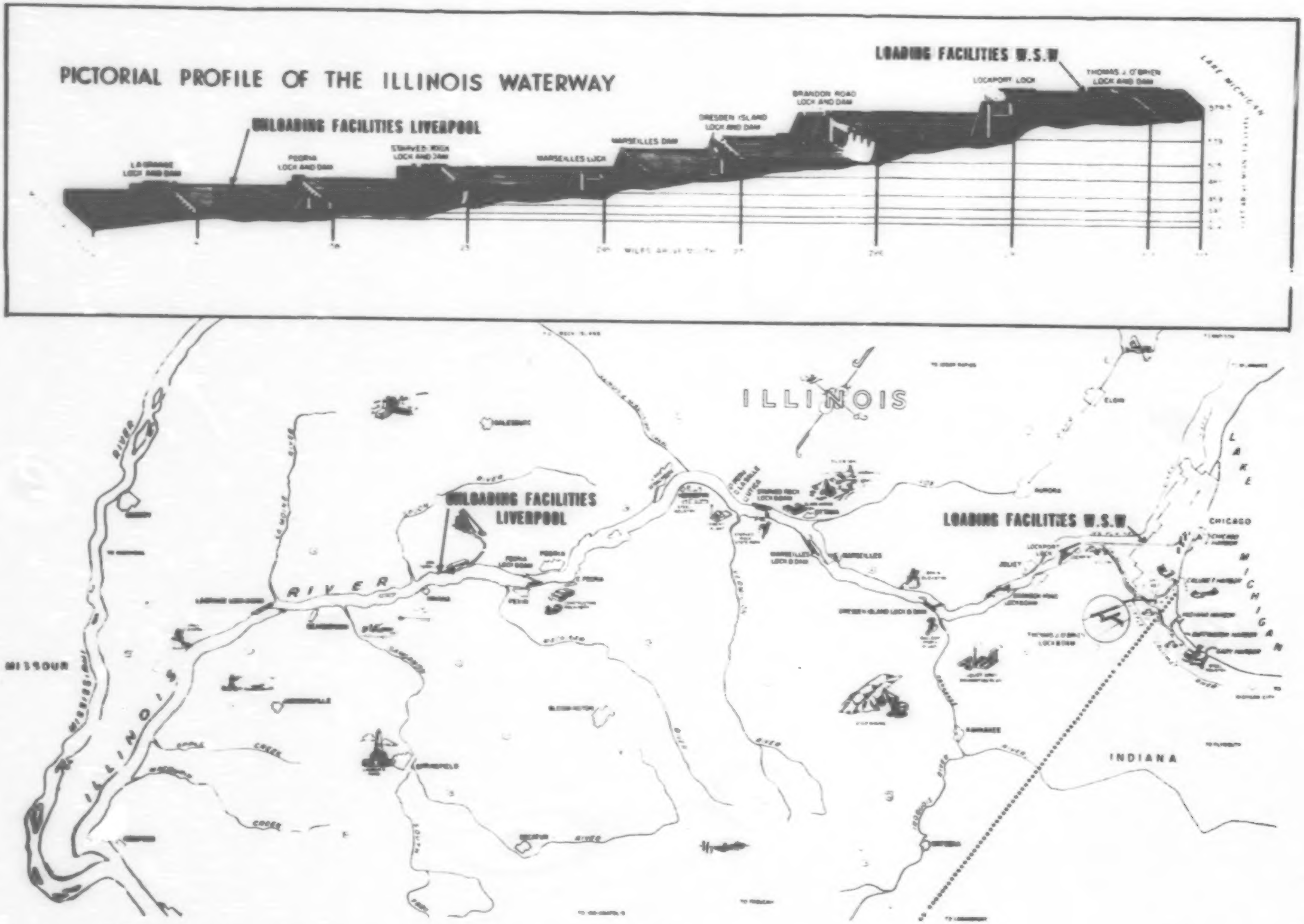
PICTORIAL PROFILE OF THE ILLINOIS WATERWAY
LOADING FACILITIES W.S.W
UNLOADING FACILITIES LIVERPOOL
LA GRANGE LOCK AND DAM
PEORIA LOCK AND DAM
STARVED ROCK LOCK AND DAM
MARSEILLES LOCK
MARSEILLES DAM
DRESDEN ISLAND LOCK AND DAM
BRANDON ROAD LOCK AND DAM
LOCKPORT LOCK
THOMAS J. O'BRIEN LOCK AND DAM
LAKE MICHIGAN
MILES ABOVE MOUTH
ILLINOIS
ILLINOIS RIVER
MISSISSIPPI RIVER
MISSOURI
INDIANA
LAKE MICHIGAN
CHICAGO
LOADING FACILITIES W.S.W
UNLOADING FACILITIES LIVERPOOL
PEORIA
JOLIET
LOCKPORT
AURORA
ELGIN
KANKAKEE
SPRINGFIELD

Figure III-1. Barging Route to Fulton County (Dalton and Murphy, 1973)

The supernatant in the upper layer of sludge in the holding basins is partially barged back to the head end of the West-Southwest treatment plant. Past sludge shipments between the West-Southwest plant or Lawndale lagoons and the holding basins are shown in Figure III-3.

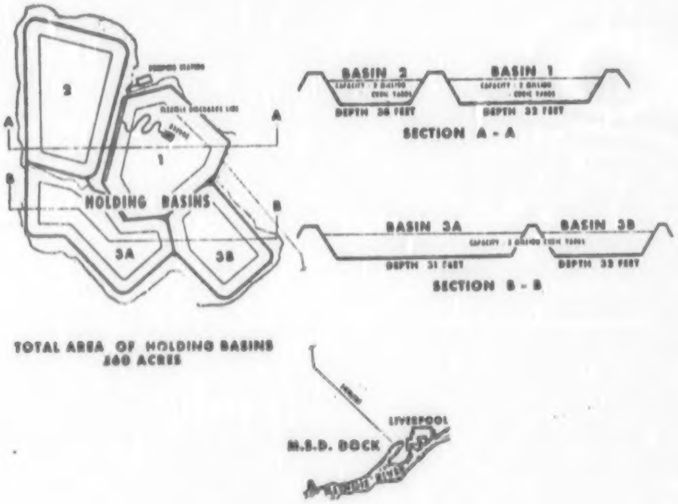
2
1
3A
3B
A
A
B
B
HOLDING BASINS
BASIN 2
DEPTH 36 FEET
BASIN 1
DEPTH 32 FEET
SECTION A - A
BASIN 3A
DEPTH 31 FEET
BASIN 3B
DEPTH 33 FEET
SECTION B - B
TOTAL AREA OF HOLDING BASINS
260 ACRES
LIVERPOOL
M.S.D. DOCK

Figure III-2. Holding Basins for Storage of Sewage Sludge (Dalton and Murphy, 1973)

During the storage periods, sludge particles settle to the bottom of the holding basins, creating two layers of liquid. The top layer ranges from 14 to 18 feet in depth and is composed of supernatant containing 1% solids. The bottom layer consists of thickened and compacted sludge with solids up to 12%. During periods of storage, it is likely that at least one-fifth of the nitrogen in the sewage is lost to the atmosphere in the form of ammonia.

Typical vertical profiles of sludge characteristics in the holding basins are shown in Figure III-4. Profiles are presented for three holding basins and seven parameters. In general, pH values remain con-

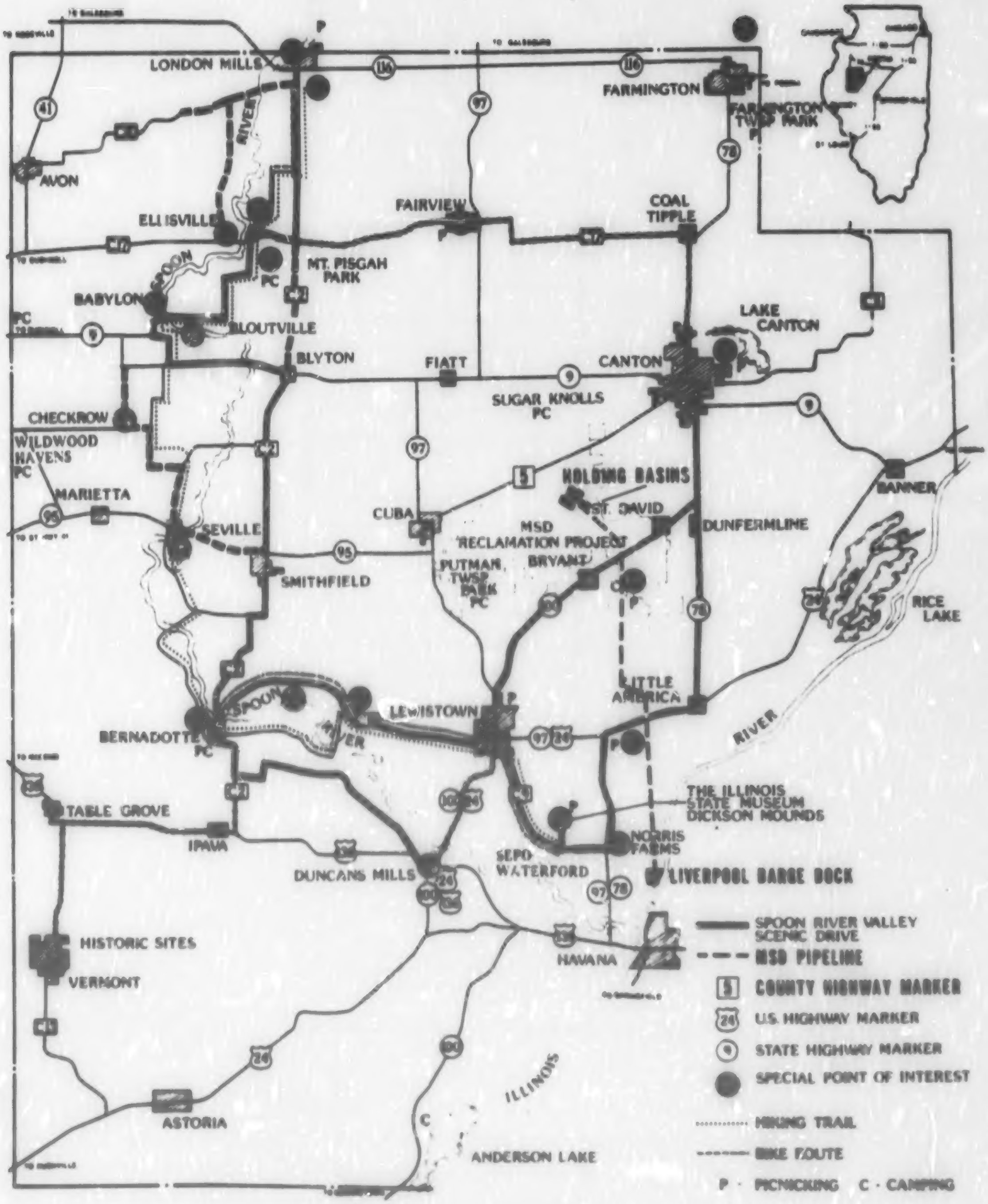
LONDON MILLS
FARMINGTON
FARMINGTON TWSP PARK
AVON
ELLISVILLE
FAIRVIEW
COAL TIPPLE
MT. PISGAH PARK
BABYLON
BLOUTVILLE
BLYTON
FIATT
CANTON
LAKE CANTON
SUGAR KNOLLS PC
CHECKROW
WILDWOOD HAVENS PC
MARIETTA
HOLDING BASINS
ST. DAVID
DUNFERMLINE
BANNER
CUBA
MSD RECLAMATION PROJECT
BRYANT
SEVILLE
SMITHFIELD
PUTMAN TWSP PARK PC
RICE LAKE
LITTLE AMERICA
SPOON
RIVER
LEWISTOWN
BERNADOTTE PC
THE ILLINOIS STATE MUSEUM DICKSON MOUNDS
TABLE GROVE
IPAVA
DUNCANS MILLS
SEPO WATERFORD
NORRIS FARMS
LIVERPOOL BARGE DOCK
HISTORIC SITES
VERMONT
HAVANA
ILLINOIS
ASTORIA
ANDERSON LAKE
SPOON RIVER VALLEY SCENIC DRIVE
MSD PIPELINE
COUNTY HIGHWAY MARKER
U.S. HIGHWAY MARKER
STATE HIGHWAY MARKER
SPECIAL POINT OF INTEREST
HIKING TRAIL
BIKE ROUTE
P · PICNICKING C · CAMPING

Figure III-2B. Unloading Dock, Pipeline Routing, and Holding Basins.

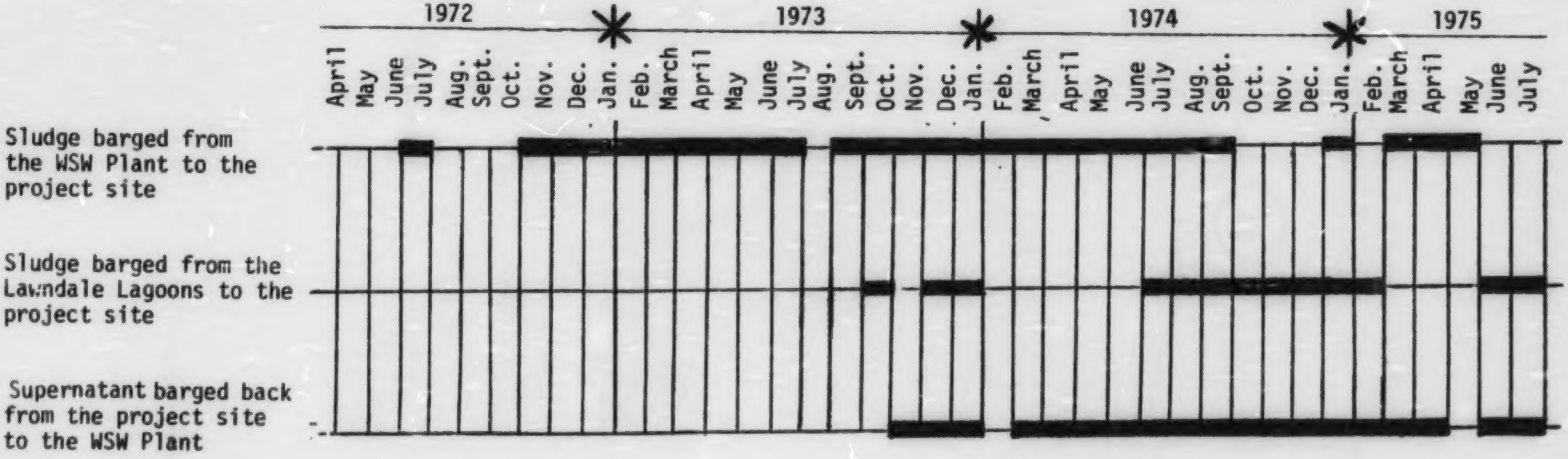

Figure III-3. Past Sludge Shipments between West-Southwest Plant Lawndale Lagoons, and Holding Basins at Project Site (MSDGC, 1972 a,b, 1973 a through h, 1974 a through 1, 1975 a through g)

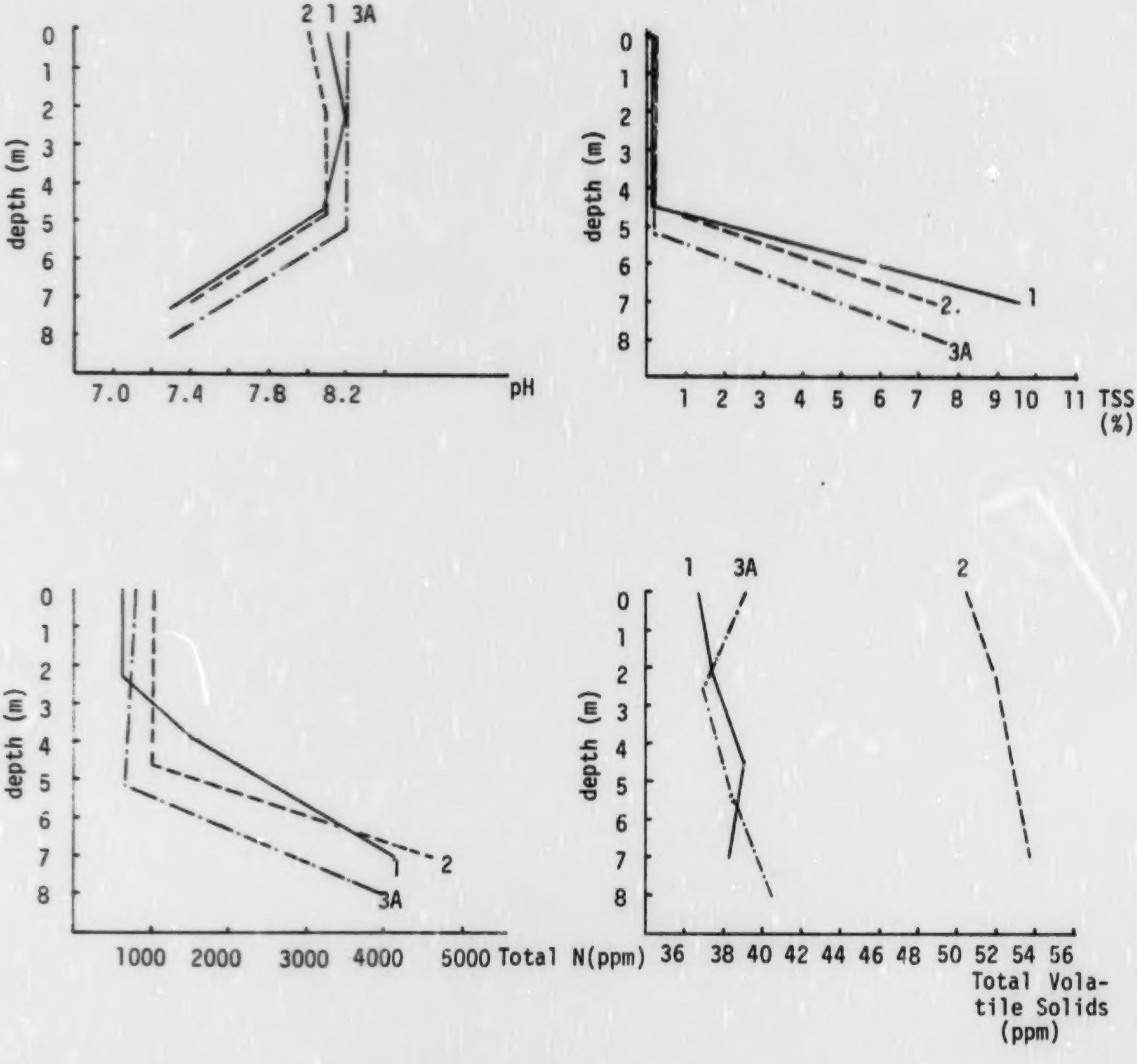

Figure III-4. Typical Vertical Profiles of Characteristics of Sludge in Holding Basins 1, 2 and 3A, April 1975 (MSDGC, 1975 d)

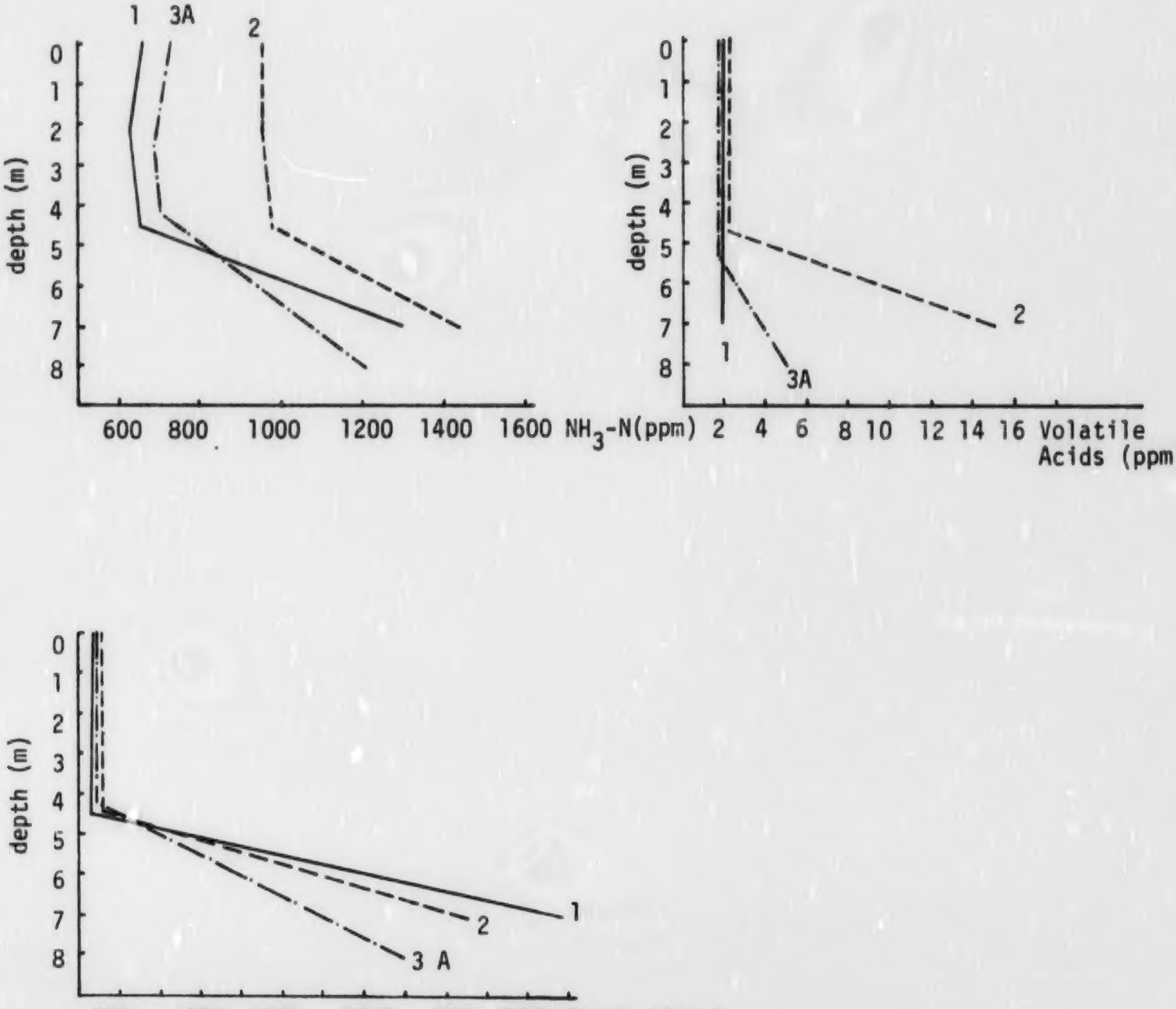

Figure III-4. (Continued)

stant in the top 5 meters and then decrease with depth. Because large proportions of nitrogen and phosphorous compounds are associated with suspended solids which settle in the basins, the total suspended solids, total nitrogen, and total phosphorous concentrations are highest at the bottom of the holding basins. The same pattern of ammonia nitrogen concentration, which is constant in the top 5 meters and then increases with depth, is recorded for all three basins. Generally speaking, the total volatile solids and volatile acids are slightly enriched at the bottom of the basins.

3. Application Methods and Amounts

Before application, conventional dredge equipment (Figure III-5) is used to mix the concentrated bottom sludge with the upper layer of supernatant. The mixture usually contains solids of 6% or less (Dalton and Murphy, 1973).

The sludge is pumped from the holding basins via a piped distribution system and applied to the land by a number of techniques. Field application devices available at the site include: traveling sprayer, center-pivot sprayer, moldboard plow incorporator, tandem disk incorporator, chisel plow incorporator, and gated irrigation pipe (MSDGC, 1975i). Sludge spraying is accomplished by modular units consisting of pumps, an above-ground header system, and a "big gun" spray vehicle (Figure III-6). The pumps and header system can be adapted to other types of irrigation vehicles. To prevent clogging, the nozzle of the spray gun has a 2-inch diameter or larger. The pressure and spray rate are 90 psi and 600 gpm, respectively, and the horizontal throw is approximately 120 to 150 feet (MSDGC, 1975i). The travel scheme of the sprayer vehicle is shown in Figure III-7.

Two types of tillage machines are used to incorporate sludge into soil -- the moldboard plow incorporator and the tandem disk incorporator (Figure III-6 shows the latter). Sludge is incorporated into soil by the disk machine with a distribution manifold which directs

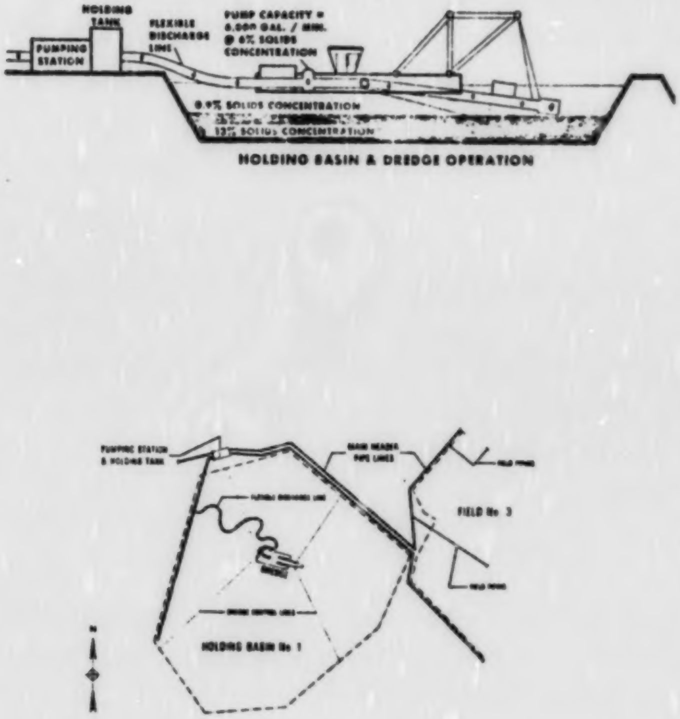
HOLDING TANK
PUMPING STATION
FLEXIBLE DISCHARGE LINE
PUMP CAPACITY = 6.000 GAL. / MIN. @ 6% SOLIDS CONCENTRATION
0.9% SOLIDS CONCENTRATION
12% SOLIDS CONCENTRATION
HOLDING BASIN & DREDGE OPERATION
PUMPING STATION & HOLDING TANK
MAIN HEADER PIPE LINES
FIELD No 3
HOLDING BASIN No 1

Figure III-5. Holding Basin, Dredge Operation, and Distribution System (Dalton and Murphy, 1973)

Reproduced from
best available copy.

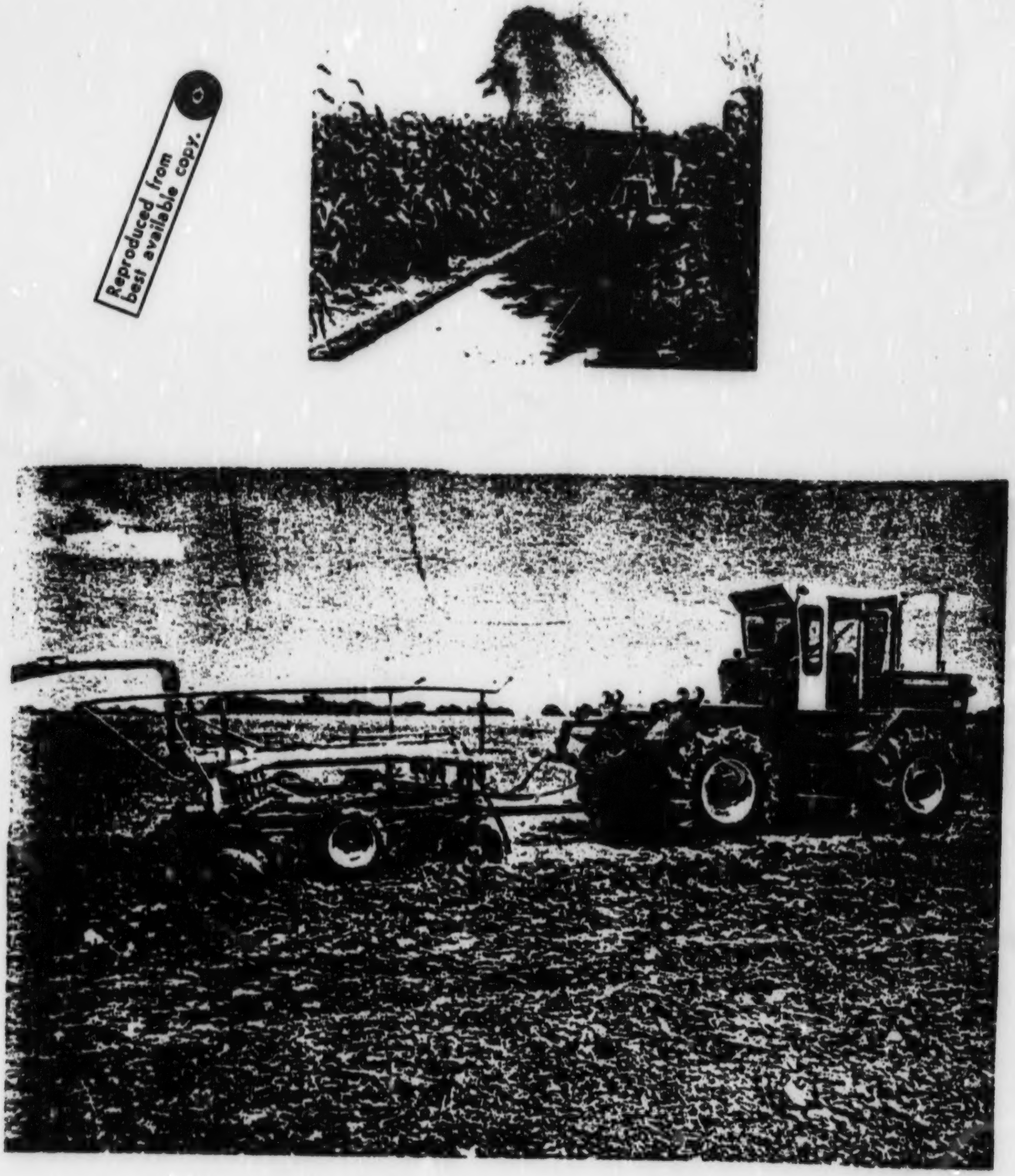

Figure III-6. Traveling Sprayer Applying Liquid Sludge to a Corn Crop (top) and Disk Incorporation with Trailing Supply Hose (MSDGC, 1975h)

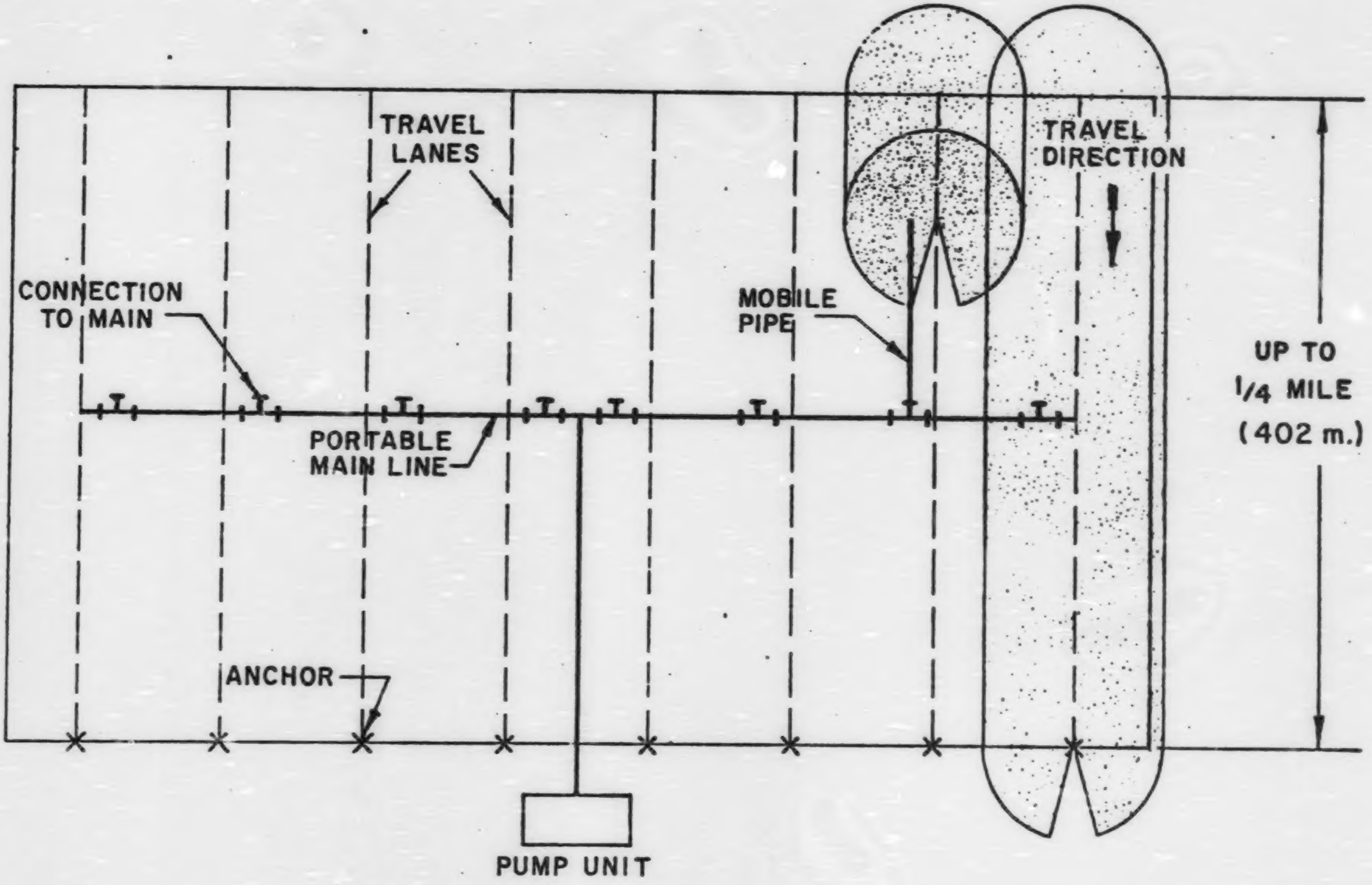
TRAVEL LANES
TRAVEL DIRECTION
CONNECTION TO MAIN
MOBILE PIPE
UP TO 1/4 MILE (402 m.)
PORTABLE MAIN LINE
ANCHOR
PUMP UNIT

Figure III-7. Travel Scheme of Sprayer Vehicle (MSDGC, 1975h)

sludge to each disk blade as it tills the soil. Sludge is thereby applied to the entire cross-sectional area of the soil being tilled. The soil injector (Figure III-8) works on the same principle as the soil incorporator, except that an injector applies sludge to slots formed in the soil by a tool shank.

A total of 43 application fields were developed from 1971 to 1973 in eight stages, varying in size from 15 to 150 acres (Figure III-9). Each field is provided with runoff berms and one or more runoff retention basins to divert and contain storm runoff and to control the water quality of field effluents. Runoff basins are number coded; for example, B-22-2 means runoff basin #2 of field #22 (MSDGC, 1972c through g, and 1973 m through o).

Sludge is applied to the fields from early spring to late fall. Periods of sludge application to various fields are shown schematically in Figure III-10. Work hours are approximately 8 hours per day at the beginning of the application season, increase to a maximum of 16 hours per day in May, and taper off to 8 hours per day at the end of the season. Application on one field is completed before beginning on another field. It takes one hour to complete application on 2 acres of land (MSDGC, 1975j). The sludge application rate in dry tons per acre and total tonnage of sludge applied per year are summarized in Table III-1. The goals of sludge application for 1974 and 1975 are presented in Figures III-11 and III-12, respectively.

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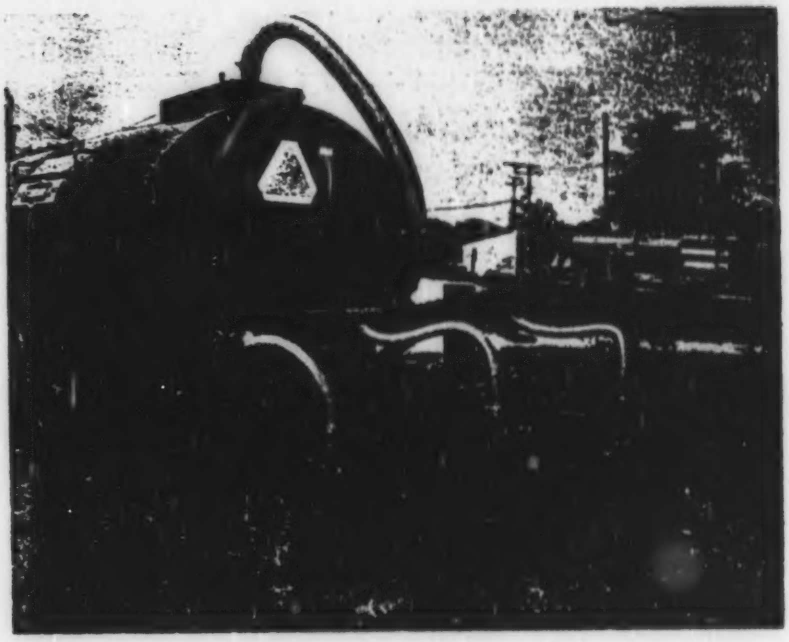


Figure III-8. Injection Unit Showing Three Injectors (MSDGC, 1975h)

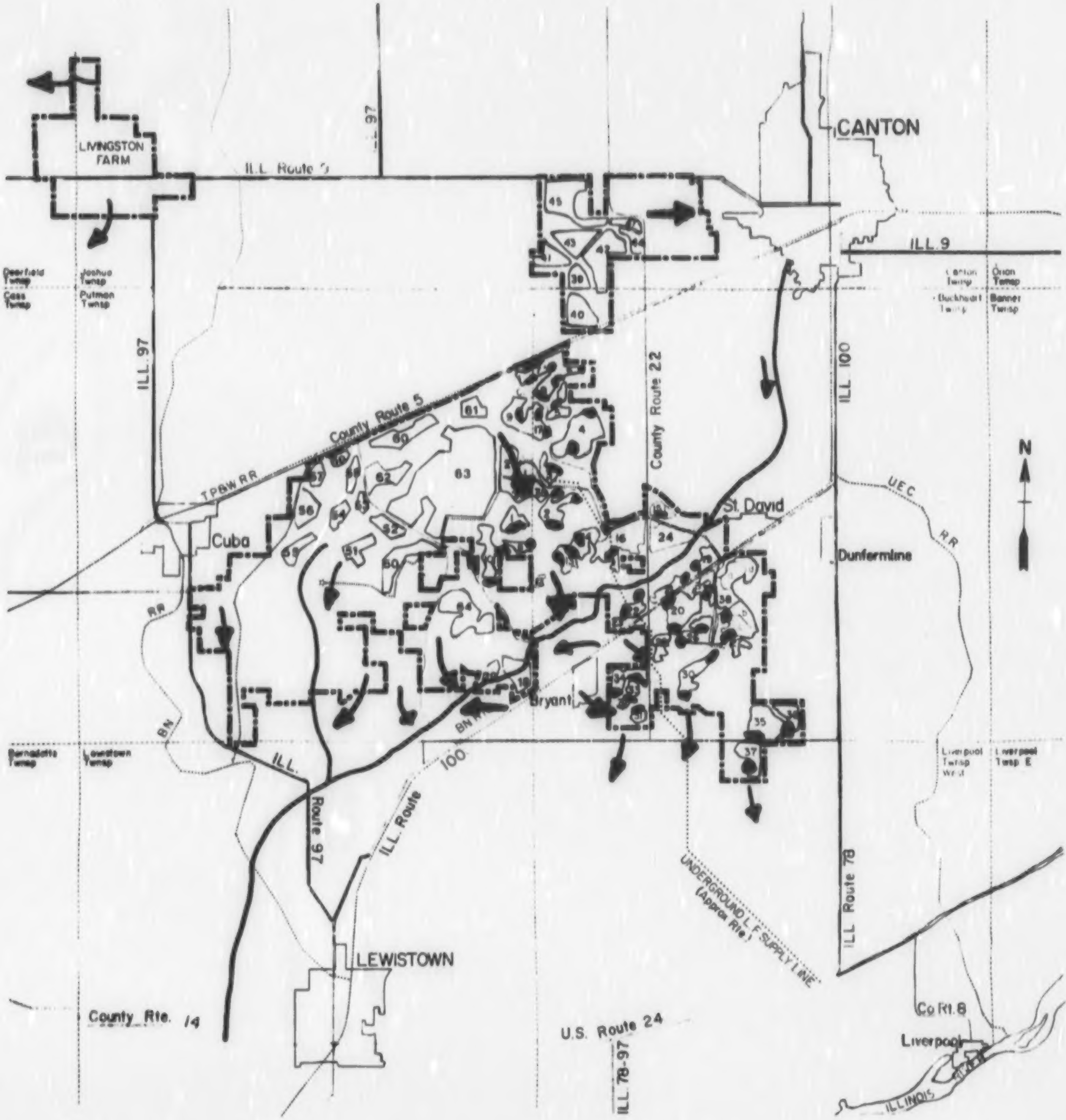

LIVINGSTON FARM
ILL. Route 5
ILL. 97
CANTON
ILL. 9
Deerfield Twnsp
Joshua Twnsp
Cass Twnsp
Putman Twnsp
Canton Twnsp
Orion Twnsp
Buckheart Twnsp
Banner Twnsp
ILL. 97
County Route 22
ILL. 100
County Route 5
TPBW RR
Cuba
St. David
Dunfermline
UEC RR
N
RR
BN
45
43
42
44
41
39
40
61
60
63
4
57
58
62
56
54
53
52
55
51
50
16
24
64
20
38
30
18
34
37
35
Bryant
BN RR
ILL. Route 97
ILL. Route 100
Bernadotte Twnsp
Lewistown Twnsp
Liverpool Twnsp West
Liverpool Twnsp E
ILL. Route 78
UNDERGROUND L.F. SUPPLY LINE (Approx Rte.)
LEWISTOWN
County Rte. 14
U.S. Route 24
ILL. 78-97
Co Rt.8
Liverpool
ILLINOIS RIVER

Figure III-9. Sludge Application Fields at the Project Site and Their Runoff Retention Basins (MSDGC, 1975d)

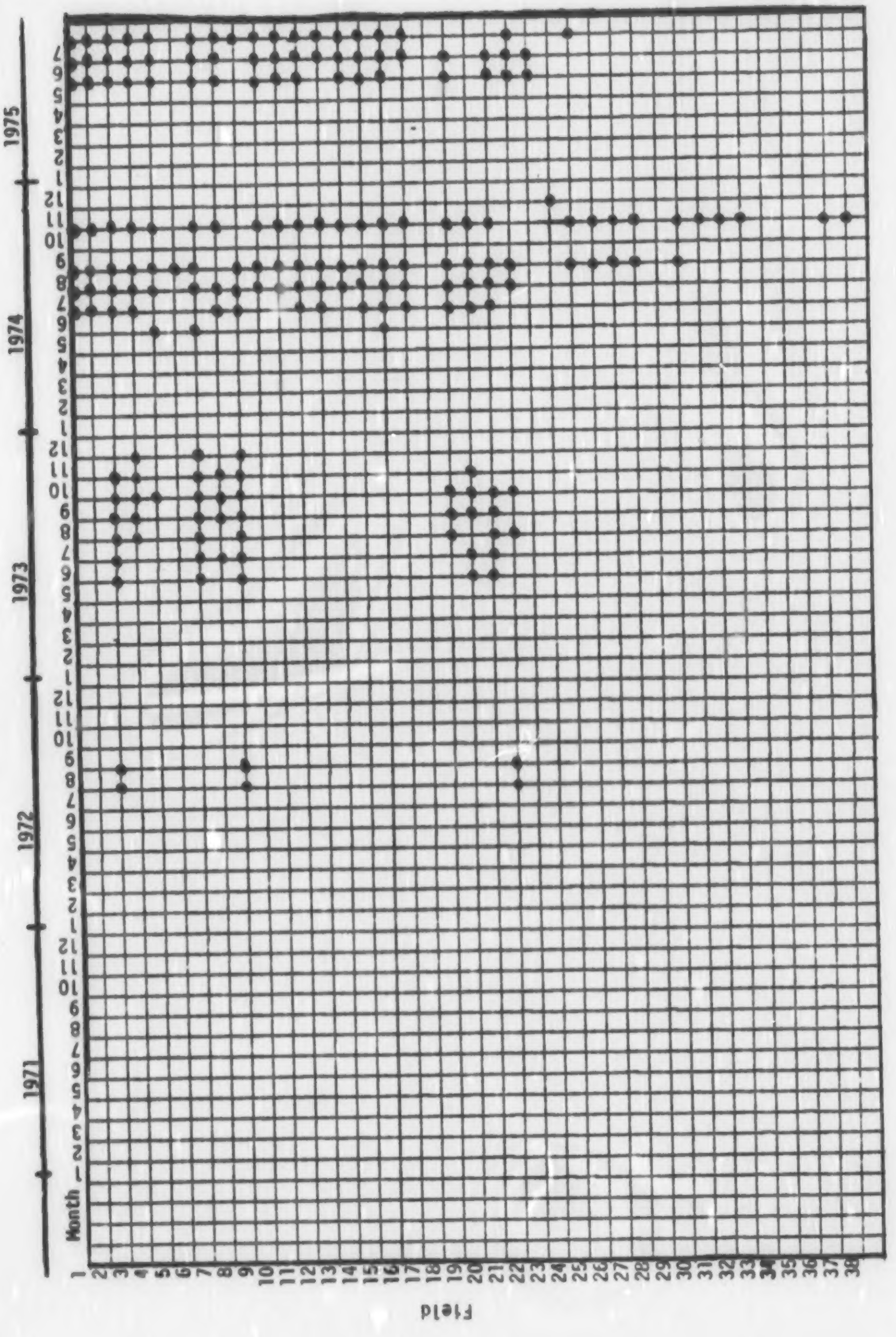


Figure III-10. Periods of Sludge Application to Fields in Fulton County

Table III-1. Sludge Application Rates and Amounts
(MSDGC - 1973 a through h,
1974 a through l,
1975 a through q)

Field	Field Size (acres)	Year 1973		Year 1974		Year 1975 (May, June & July)	
		dt/acre	dt	dt/acre	dt	dt/acre	dt
1	46	--	--	19.0	874.0	19.5	897.0
2	52	--	--	24.0	1,248.0	14.8	769.6
3	41	1.21	49.6	24.4	1,000.4	3.5	143.5
4	80	0.50	40.0	24.5	1,960.0	19.9	1,592.0
5	30	0.58	17.4	23.2	696.0	29.1	873.0
6	15	--	--	0.2	3.0	--	--
7	110	0.49	53.9	21.3	2,343.0	13.4	1,474.0
8	71	0.95	67.5	12.1	859.1	17.7	1,256.7
9	93	2.38	221.3	16.3	1,515.9	6.7	623.1
10	94	--	--	25.8	2,425.2	16.6	1,500.4
11	21	--	--	29.4	617.4	27.4	575.4
12	27	--	--	17.0	459.0	16.3	440.1
13	36	--	--	16.2	583.2	7.7	277.2
14	70	--	--	6.6	462.0	6.9	483.0
15	22	--	--	29.1	640.2	27.7	609.4
16	150	--	--	17.6	2,640.0	14.9	2,235.0
17	88	--	--	19.2	1,689.6	9.4	827.2
19	38	1.35	51.3	16.4	623.2	14.6	554.8
20	114	0.37	42.2	23.4	2,667.6	--	--
21	39	1.50	58.5	27.2	1,060.8	17.7	690.3
22	52	0.57	29.6	6.3	327.6	17.5	910.0
23	22	--	--	--	--	7.3	160.6
24	--	--	--	0.5	--	--	--
25	38	--	--	9.7	368.6	11.3	429.4
26	64	--	--	27.3	1,747.2	--	--
27	43	--	--	20.2	868.6	--	--
28	31	--	--	17.2	533.2	--	--
30	69	--	--	20.1	1,386.9	--	--
31	18.5	--	--	8.4	155.4	--	--
32	15	--	--	3.6	54.0	--	--
33	19	--	--	4.1	77.9	--	--
37	68.9	--	--	7.2	496.8	--	--
38	54.2	--	--	1.9	103.0	--	--

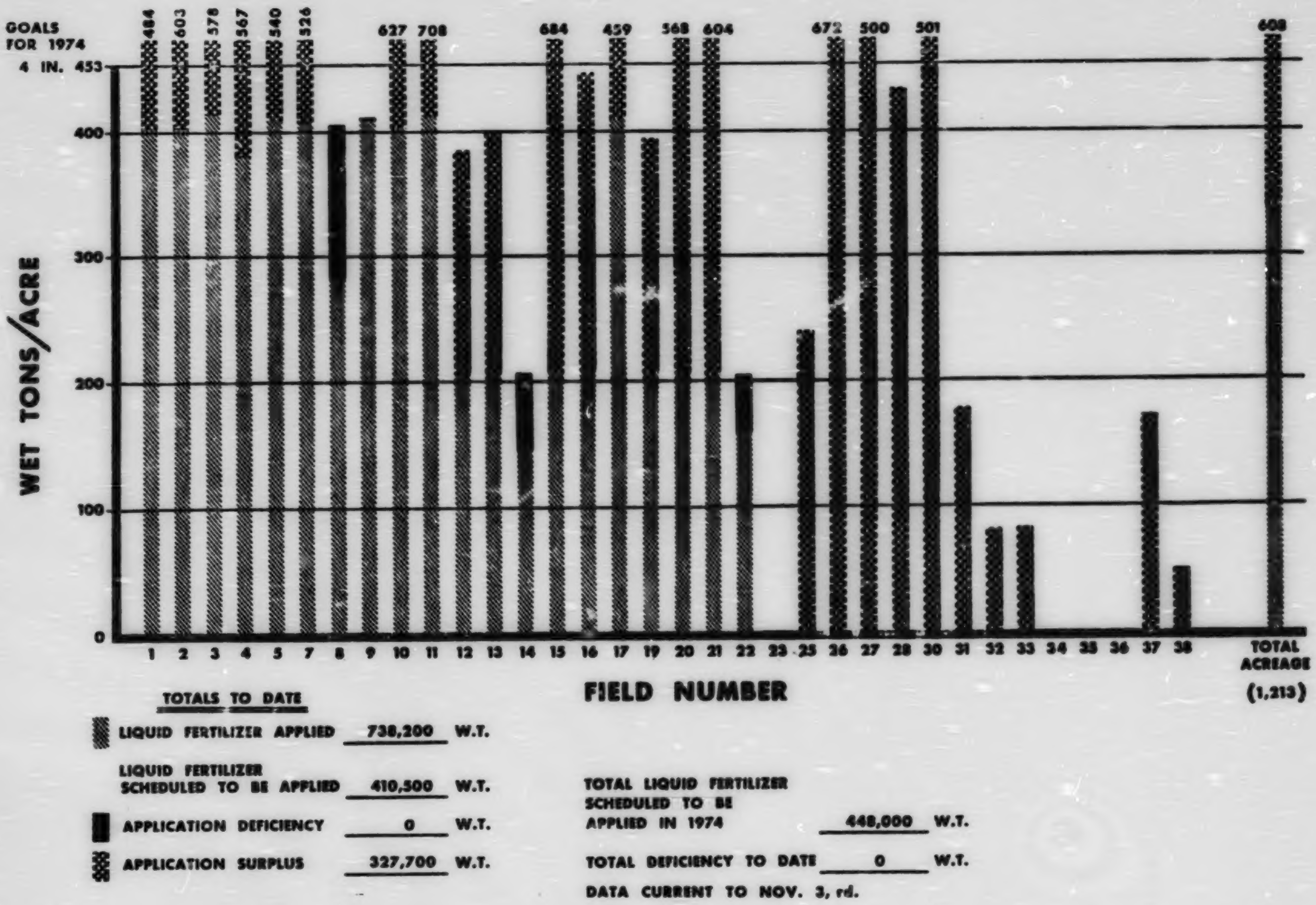
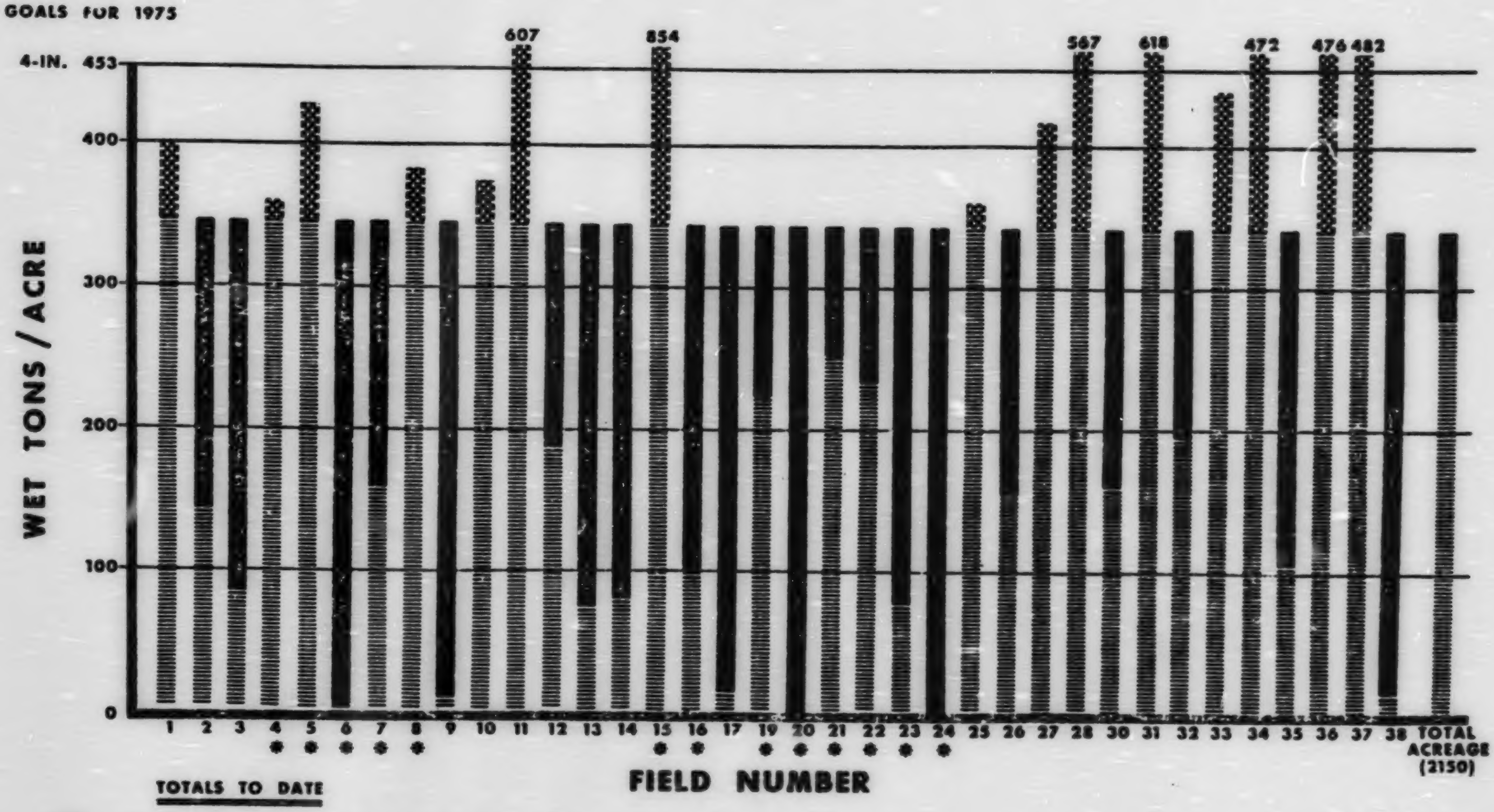


Figure III-11. Fulton County Sewage Sludge (Liquid Fertilizer) Application Progress and Goals for 1974



TOTALS TO DATE

■ LIQUID FERTILIZER APPLIED 594,088 W.T.

LIQUID FERTILIZER SCHEDULED TO BE APPLIED 732,400 W.T.

■ APPLICATION DEFICIENCY 138,312 W.T.

▩ APPLICATION SURPLUS 0 W.T.

*NON-SPRAY APPLICATION

TOTAL LIQUID FERTILIZER SCHEDULED TO BE APPLIED IN 1975 973,600 W.T.

TOTAL DEFICIENCY TO DATE 138,312 W.T.

DATA CURRENT TO AUG. 9,1975

Figure III-12. Fulton County Sewage Sludge (Liquid Fertilizer) Application Progress and Goals for 1975

B. ENVIRONMENTAL CONTROL AND MONITORING SYSTEMS

To ensure against environmental degradation resulting from project operation, some systems for protection were incorporated into the project during the planning and development stages. These include lining of holding basins to prevent groundwater contamination from seepage or percolation of sludge, control berms and basins to contain storm runoff from each field and to control water quality of field effluents, and terracing and grading of fields to reduce runoff velocity, erosion and sedimentation. The effectiveness of these control systems and the environmental soundness of project operations have been monitored using five systems pertaining to sludge, water, soil and rock, plants and aquatic biota, and air.

1. Holding and Runoff Basins

The holding basins were constructed following the engineering recommendations which concluded a subsurface investigation and evaluation (A&H Engineering Corporation, 1971). The interior of a holding basin was contoured to take advantage of the natural grade. No slopes within the basins are steeper than 1:5. A continuous compact earth lining was constructed within the perimeter of the basin enbankment to prevent groundwater contamination. The earth lining has a minimum 2-foot thickness of compact clay. The degree of compaction is specified in the subsurface study report.

The fields were contoured or terraced and retention berms or slotted application standpipes constructed at the tops of the terrace underdrains. These features were designed to retain storm runoff in the fields long enough to allow most of the silt to settle in the fields rather than wash into the retention basins. A typical runoff retention basin is shown in Figure III-13. Runoff retained in the basins is not released unless it meets applicable water quality standards. Runoff of substandard quality can be recycled by pumping it back on the fields.

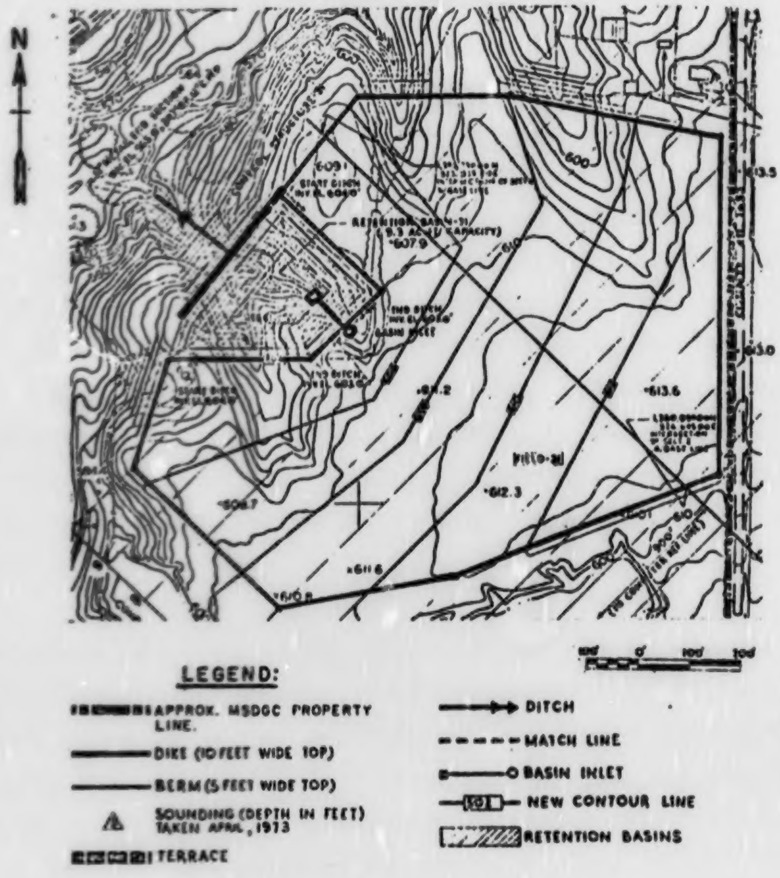

N
600
610
613.5
613.0
614.2
613.6
612.3
611.6
608.7
607.9
609.1
100' 0' 100' 200'
LEGEND:
APPROX. MSDGC PROPERTY LINE.
DIKE (10 FEET WIDE TOP)
BERM (5 FEET WIDE TOP)
SOUNDING (DEPTH IN FEET) TAKEN APRIL, 1973
TERRACE
DITCH
MATCH LINE
BASIN INLET
NEW CONTOUR LINE
RETENTION BASINS

Figure III-13. Typical Storm Runoff Retention Basin (MSDGC, 1973n)

In Figure III-14, retention berms and basins, terraces and dikes, basin inlet and outfall, and outfall control structures are shown for a typical field. The original and modified contours are also indicated.

2. Sludge and Water Monitoring

To ensure adequate treatment of sludge before it is transported to the holding basins at the project site, the sludge quality must comply with standards as specified in the project's operating permit. A sludge analysis program was designed for this purpose. Twenty-four hour composite samples of sludge being barged to the project site are analyzed. In addition to measuring the volatile acids, pH value, total alkalinity and volatile solids, as required by the permit, total solids, total phosphorus, Kjeldahl nitrogen, ammonia nitrogen, and electrical conductivity are determined for each composite sample. Occasionally, concentrations of chloride, sulfate, and 14 metal elements are determined. The supernatants returned from the holding basins are sampled and analyzed to the same extent. A typical data log is presented in Table III-2. A detailed discussion of the results is given in Section VII.A.

The water monitoring system includes water sampling, analysis, data reporting and data reduction. Water samples are taken from 26 wells, 1 spring, 11 stream sampling stations located on eight creeks or streams, effluent sampling stations at runoff basins, and at a number of reservoirs. The locations of sampling stations are indicated in Figure III-15. Water quality parameters analyzed and reported on include:

- Physical parameters such as total suspended solids (TSS), total dissolved solids (TDS), total volatile solids (TVS), electrical conductivity, and temperature
- Chemical parameters such as pH, total alkalinity, dissolved oxygen (D.O.), total phosphorus (P), total Kjeldahl nitrogen (N), ammonia nitrogen (NH_3-N), nitrate and nitrate nitrogen (NO_2+NO_3-N)
- Anions such as chloride (Cl) and sulfate (SO4) and cations such as potassium (K), sodium (Na), calcium (Ca), and magnesium (Mg)

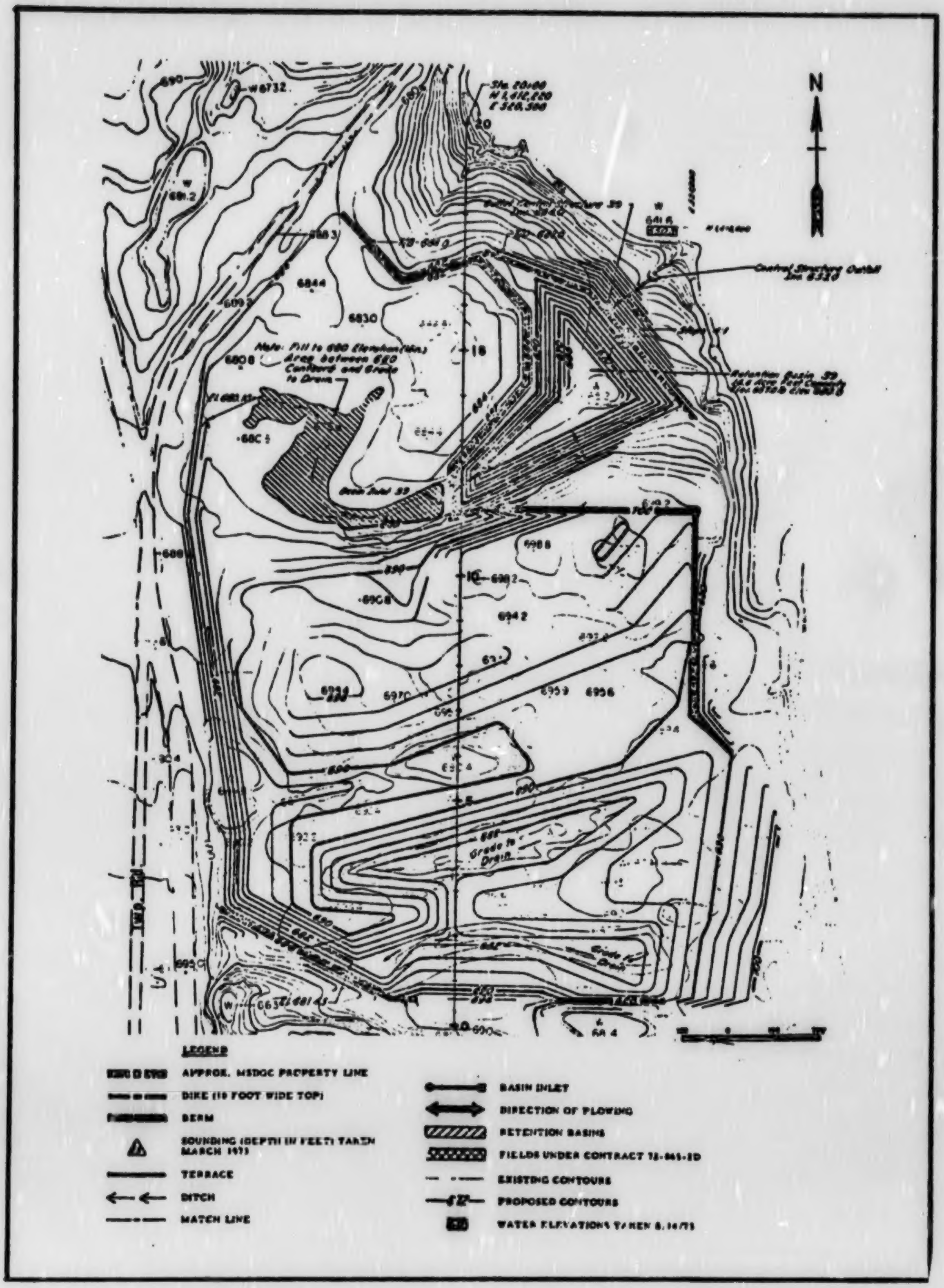

N
Note: Fill to 680 Elevation (Min.) Area between 680 Contour and Grade to Drain
Grade to Drain
Grade to Drain
Control Structure Outfall
Retention Basin 39
LEGEND
APPROX. MSDGC PROPERTY LINE
DIKE (10 FOOT WIDE TOP)
BERM
SOUNDING (DEPTH IN FEET) TAKEN MARCH 1973
TERRACE
DITCH
MATCH LINE
BASIN INLET
DIRECTION OF PLOWING
RETENTION BASINS
FIELDS UNDER CONTRACT 73-045-2D
EXISTING CONTOURS
PROPOSED CONTOURS
WATER ELEVATIONS TAKEN 8.14/73

Figure III-14. Drainage Control Features of a Typical Field (MSDGC, 1973n)

Table III-2. Fulton County Land Reclamation Project Sewage Sludge Analysis, April 1975 (MSDGC, 1975g)

	MDL*	Date 4/3	 4/5	 4/6	 4/7
Total Solids %		3.72	3.38	3.37	3.42
Total Volatile Solids %		52.62	54.15	55.68	54.62
Volatile Acids** (mg/l)		67.00	67.00	45.00	90.00
pH		7.40	7.50	7.80	7.60
Total P (mg/l)	0.01	980.00	830.00	1,010.00	890.00
Cl- (mg/l)	1.0	292.00			404.00
$SO_4^=$ (mg/l)	1.0				
N-Kjeldahl (mg/l)	1.0	2,849.00	2,681.00	2,513.00	2,632.00
NH_3-N (mg/l)	1.0	1,344.00	1,372.00	1,421.00	1,435.00
Alkalinity as $CaCO_3$ (mg/l)	0.1	3,900.00	4,780.00	4,920.00	4,940.00
Electrical Conductivity (μmhos/cm)	1.0	7,300.00	8,000.00	7,500.00	8,000.00
Al (mg/l)	1.0	220.00			200.00
Cd (mg/l)	0.01	7.00			7.00
Ca (mg/l)	1.0	1,200.00			1,010.00
Cr (mg/l)	0.02	93.80			86.90
Cu (mg/l)	0.01	48.00			48.80
Fe (mg/l)	0.1	1,370.00			1,652.00
Pb (mg/l)	0.03	30.40			32.60
			(no samples taken)		
Hg (μg/l)	0.1	151.00			140.00
Mg (mg/l)	1.0	500.00			490.00
Mn (mg/l)	0.01	13.20			14.80
Ni (mg/l)	0.1	13.00			13.00
K (mg/l)	1.0	220.00			200.00
Na (mg/l)	1.0	110.00			150.00
Zn (mg/l)	0.1	115.00			98.00

*MDL = minimum detection limit of laboratory.
**As acetic acid.

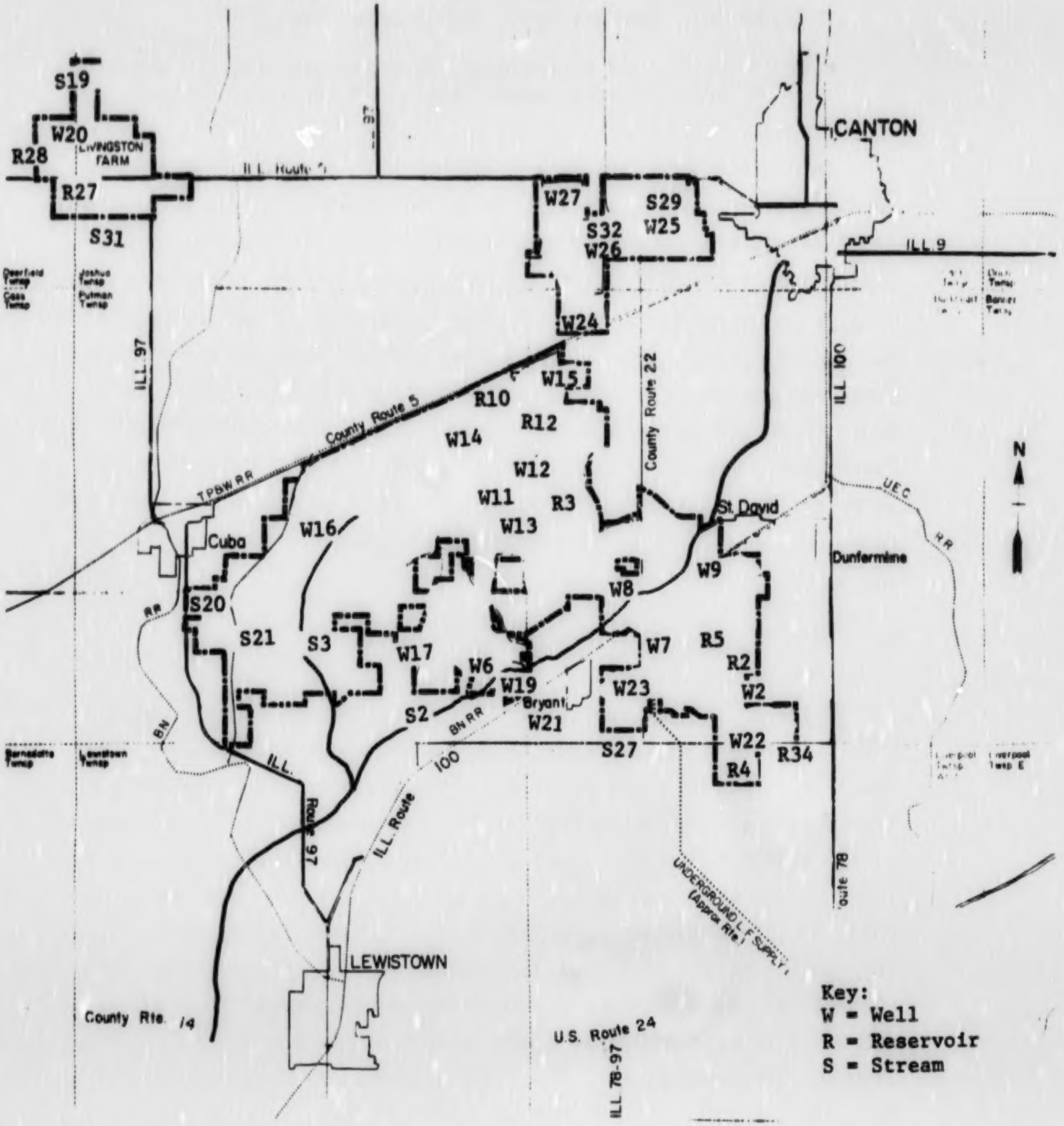

S19
W20
R28
LIVINGSTON FARM
R27
S31
ILL. Route 5
37
CANTON
W27
S29
W25
S32
W26
ILL. 9
W24
ILL. 97
W15
R10
R12
County Route 5
W14
W12
County Route 22
ILL. 100
W11
R3
W13
TP&W RR
St. David
UEC RR
N
Cuba
W16
W9
Dunfermline
W8
RR
S20
S21
S3
W17
W7
R5
W6
R2
W19
W23
W2
Bryant
S2
BN RR
W21
W22
S27
R34
BN
R4
ILL.
100
ILL. Route
Route 97
UNDERGROUND L.F. SUPPLY (Approx Rte.)
Route 78
LEWISTOWN
County Rte. 14
U.S. Route 24
ILL. 78-97
Key:
W = Well
R = Reservoir
S = Stream

Figure III-15. Water Monitoring Locations in Fulton County (MSDGC, 1975d)

- Trace metals such as zinc (Zn), cadmium (Cd), copper (Cu), chromium (Cr), manganese (Mn), lead (Pb), iron (Fe), aluminum (Al), mercury (Hg), and selenium (Se)
- Biological and microbiological parameters such as 5-day biological oxygen demand (BOD_5) and fecal coliforms.

In addition, groundwater elevations have been observed and recorded monthly. Water samples are collected and examined every month, and findings are summarized in a monthly report entitled Environmental Protection System Report for Fulton County, Illinois. Typical examples of data are given in Tables III-3 and III-4. The former table reports the quality of well, reservoir, spring and stream waters; the latter shows the qualify of effluent from retention basins. Samples taken prior to project operation constitute baseline information for the "no-action" water quality situation. Changes are revealed by comparing water quality resulting from project operation with the baseline data. Detailed discussions in this regard are presented in sections VII.D. and VII.E.

3. Soil, Biota and Air Monitoring

Prior to project operation, 52 soil borings to bedrock approximately 40 feet deep were made to determine the physical and chemical Characteristics of soils and rock. Physical tests included the penetration test, strength test, density test, compressibility test, permeability test, and field pumping tests. Stratigraphs of types of soils and their geographical distribution were established. The texture, color, moisture content, grain size distribution, and permeability of the spoil material were analyzed (A&H Engineering Corporation, 1971). Chemical analyses included exchangeable calcium, organic carbon, and hydrochloric acid-extractable metals such as manganese, zinc, copper, cadmium, chromium, nickel, lead, and aluminum, for both spoils and place land (MSDGC, 1975h). It was proposed that, 5 years after project initiation (1977), another set of soil borings would be made to bedrock to investigate changes in soil chemistry (Dalton and Murphy, 1973). Detailed discussions on these data can be found in sections IV.B. and VII.F.

Table III-3. Fulton County Land Reclamation Project
Water Analysis, April 1975 (MSDGC, 1975g)

			Well Data		Reservoir Data		Stream & Spring Data		
Sampling Stations:			W1	W2	R1	R2	SPR	S1	S2
DATE:		MDL*	4/ 7	4/ 7	4/ 9	4/ 9	4/ 7	4/16	4/16
PH			7.20	7.40	7.80	8.10	7.70	7.80	7.80
TOTAL P	MG/L	0.01	0.15	0.38	0.09	0.13	0.10	0.56	0.33
CL-	"	1.0	15.00	21.00	9.00	12.00	15.00	29.00	27.00
SO4=	"	1.0	192.00	67.00	485.00	493.00	1383.00	360.00	501.00
N-KJELDAHL	"	0.5	0.80	1.30	1.50	1.50	0.80	2.40	2.30
N-NH3	"	0.1	0.70	1.10	0.40	0.30	0.80	1.40	0.90
N-NO2+NO3	"	0.01	0.01	0.00	3.48	2.56	0.09	3.16	3.40
ALK AS CACO3	"	1.0	390.00	420.00	360.00	470.00	500.00	260.00	240.00
ELEC.COND.	UMHOS/C		700.00	650.00	825.00	950.00	2600.00	900.00	1000.00
K	MG/L	1.0	0.00	0.00	3.00	3.00	8.00	4.00	4.00
NA	"	1.0	12.00	12.00		20.00	137.00	66.00	76.00
CA	"	1.0	121.00	121.00	135.00	165.00	528.00	130.00	135.00
MG	"	1.0	60.00	52.00	74.00	72.00	195.00	68.00	78.00
ZN	"	0.1	0.00	0.20	0.00	0.00	0.00	0.00	0.00
CD	"	0.01	0.00	0.00		0.00	0.00	0.00	0.00
CU	"	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CR	"	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NI	"	0.1	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MN	"	0.01	0.19	0.15	0.04	0.24	1.67	0.42	0.40
PB	"	0.01	0.00	0.00	0.00	0.03	0.00	0.00	0.00
FE	"	0.1	3.40	7.40	0.00	0.00	3.00	0.80	0.70
AL	"	1.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00
HG	UG/L	0.1	0.00	0.00	0.10	0.40	0.12	0.10	0.10
SE	MG/L	0.2	0.00	0.00	0.00	0.00	0.00	0.00	0.00
FC	PER 100 ML	2	0.00	0.00	0.00	2.00	0.00	7.2E+04	3900.00
D.O.	MG/L	0.5			11.40	11.50			
TEMP.	°C				3.00	4.00			
STATIC H2O EL.	FT.				2.00	5.00	10.00	37.00	16.00
BOD	MG/L				844.00	913.00	3230.00	843.00	1010.00

*MDL=MINIMUM DETECTION LIMIT OF LABORATORY. ALL VALUES LESS THAN THESE ARE REPORTED AS ZERO.

Table III-4. Retention Basin Effluent Quality (MSDGC, 1975g)

Field Runoff Basin Log at the District Site in Fulton County, Illinois

Basin number	4-1	5-1	7-3	8-1
Stage reading	35%	35%	60%	45%
Date opened/checked	9:30 a.m. 4/15	9:45 a.m. 4/15	10:15 a.m. 4/15	10:30 a.m. 4/15
R&D approval	Yes	Yes	Yes	Yes
Sampled	Yes	Yes	Yes	Yes
Date closed	3:00 p.m. 4/15	9:30 a.m. 4/17	10:15 a.m. 4/21	8:00 a.m. 4/16
No. days open	0.23	2.00	6.00	0.90
Discharge (MG)	0.04	0.31	0.72	0.42
Comments				

Field Runoff Basins - Water Analysis and Discharges at Fulton County During April 1975

Date Sampled	4-15-75	4-15-75	4-15-75	4-15-75
Source	B-2-2	B-3-1	B-4-1	B-5-1
TSS mg/l	43	38	220	33
BOD mg/l	4	8	23	7
FC per 100 ml	<10	20	<10	<10
Date discharged	4-15-75	4-15-75	4-15-75	4-15-75
Quantity MG	0.32	1.48	0.04	0.31

The chemical composition of plants grown in sludge-fertilized fields and those grown on control plots have been determined to evaluate the plants' nutrient uptake rates and to detect any buildup of chemical constituents. The analysis included samples from stalks, leaves and grain of the fertilized plants. A detailed evaluation of this data is performed in Section IX.

An ecological study of aquatic biota in streams and reservoirs was initiated in June 1971. Fish and plankton have been sampled, collected and analyzed monthly, and data reported quarterly. The fishery study includes fish population, diversity, and the body condition or "well being" of various fish species such as bluegill, large mouth bass and green sunfish. The body condition of the fish population is determined and reported by the weight-length factor or condition factor K. The plankton study of reservoir water includes plankton counts and population distribution among identified species.

Besides these ecological data, more than 38 physical, chemical, and biological parameters of the sample water are analyzed for studies of phenomena such as lake eutrophication. These include pH value, conductivity, alkalinity, solids concentrations, different forms of nitrogen compounds, total phosphorus, dissolved oxygen, water temperature, water transparency, 14 metals, and several cations (MSDGC, 1972a through 1975g; Campell and Lind, 1969; General Water Quality Standards for Illinois' Waters). Control reservoir 10 has been maintained to differentiate changes in conditions of fish and plankton from such conditions in the non-control reservoirs which receive discharges from field runoff basins.

To establish the air quality situation at the site, a meteorological station was set up close to the holding basins and an air sampling program designed. Air temperature, wind speed and direction, relative humidity and rainfall were observed daily and compiled in a monthly report. In addition to general weather observations, atmospheric ammonia concentration has been monitored at the downwind berm of the holding basins on a batch basis. During ammonia monitoring periods, average wind speed and direction, air temperature, dew point, and volume of air sampled are measured. Detailed discussions on the weather and ammonia observations as related to odor problems are presented in sections IV.A and VII.B, respectively. An example of the data log is given in Table III-5 below.

Table III-5. Atmospheric NH_3 Concentrations and Sampling Conditions at the MSDGC Liquid Fertilizer Holding Basins in Fulton County During April 1975 (MDSGC, 1975d)

Date	4-4-75	4-7-75	4-9-75	4-25-75	4-28-75
Basin	3A	2	2	3A	1
Berm	SW	SW	SW	S	N
Starting Time	1045	1030	1405	1014	1029
Total Time Minutes	90	90	90	90	90
Air Volume Sampled Liters	1201.75	1314.44	925.27	924.40	1354.30
Dew Point °C	1	2	10.5	9	16.5
Air Temperature °C	3	4	16	13	23.5
Wind Direction	N-NE	E	E	N-NW	SW
Mean Wind Speed mph	4	11	10	15	8
Atmospheric NH_3 ppm (v/v)	0.14	0.05	0.52	0.53	0.73

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MSDGC, Private Communication with Mr. Bill Macaitis, Engineer of Planning, October 1975i.

MSDGC, Private Communication with George Hall, 1975j.

IV. PRESENT CONDITIONS OF THE ENVIRONMENT

Before environmental impacts resulting from the project can be assessed, existing environmental conditions must be defined. It is evident that sewage sludge disposal will affect the physical environment of the application site and surroundings, but a project of this magnitude can also exert a major influence upon socio-economic characteristics of the entire county.

This chapter provides a description of baseline information concerning climate, topography, geology, soils, hydrology, water quality, biology and ecosystems. Past and projected trends in local population and the economy are presented along with the established and forecast land use patterns and land development potential. The chapter concludes with a discussion of natural and cultural resources in Fulton County that are particularly sensitive to planned project operations.

A. CLIMATE AND TOPOGRAPHY

Past and present climatic conditions and local meteorology must be determined in order to predict the most probable and worst conditions affecting future project operations. This analysis helps to identify potential air quality problems such as odor transmission and dispersion of airborne toxic or pathogenic materials resulting from sludge application.

The area climate, which is a record of numerous atmospheric events, must be defined by weather elements such as temperature, wind, cloud cover, solar radiation, humidity, precipitation, and atmospheric stability. Climatic data from two weather stations are used for analysis. Weather station #14842 is located at the Greater Peoria Airport approximately 25 miles east-northeast of the project site (National Climatic Center, 1974a). The second weather station was set up by the Metropolitan Sanitary District of Greater Chicago at the project site (MSDGC, 1975b).

In addition to climate, local topography is summarized in terms of characteristics which could influence the microclimate and create susceptibility to impacts on air and water quality.

1. General Meteorology

The climate of this area is typically continental, as is evidenced by the changeable weather and wide range of temperature extremes. Meterological characteristics of the project area are discussed in the following sections.

a. Temperature and precipitation - According to 40-year observations at the Peoria Airport station, the average monthly temperature varies from 25°F to 75°F, with an annual average of 51.1°F. The patterns of variation in monthly average, maximum, and minimum temperatures are shown in Figure IV-1. Using a baseline of 65°F, there is an average of 6,200 annual heating degree days and 943 cooling degree days (National Climatic Center, 1974a).

The annual rainfall, as recorded at Peoria Airport, averages 34.99 inches, with a maximum of 50.27 inches and a minimum of 23.99 inches. Variations in monthly mean, maximum, and minimum precipitation are shown in Figure IV-2. The monthly maximum and minimum rainfalls are displayed for the Peoria Airport station, but the monthly means measured at both Peoria Airport and the project site are shown for overlapping observation periods. In spite of the 25-mile distance between these two stations, the precipitation pattern is quite uniform. The maximum amount of rainfall occurring in any 24-hour period was 5.52 inches in May 1927. The predicted 24-hour rainfall patterns for Fulton County at four recurrence intervals (1-year, 5-year, 25-year, and 100-year) are presented in Table IV-1. The cumulative amount of rainfall is estimated to be 6.53 inches for a 24-hour, 100-year rain storm.

The average annual snowfall is normally 23.1 inches, with a maximum of 42.3 inches and a minimum of 7.8 inches. Variations in monthly mean, maximum, and minimum snowfalls are given in Figure IV-3. Snowfall usually begins in late September and ends in early May. December through February are freezing months during which snow accumulation is at a maximum and snow melting at a minimum.

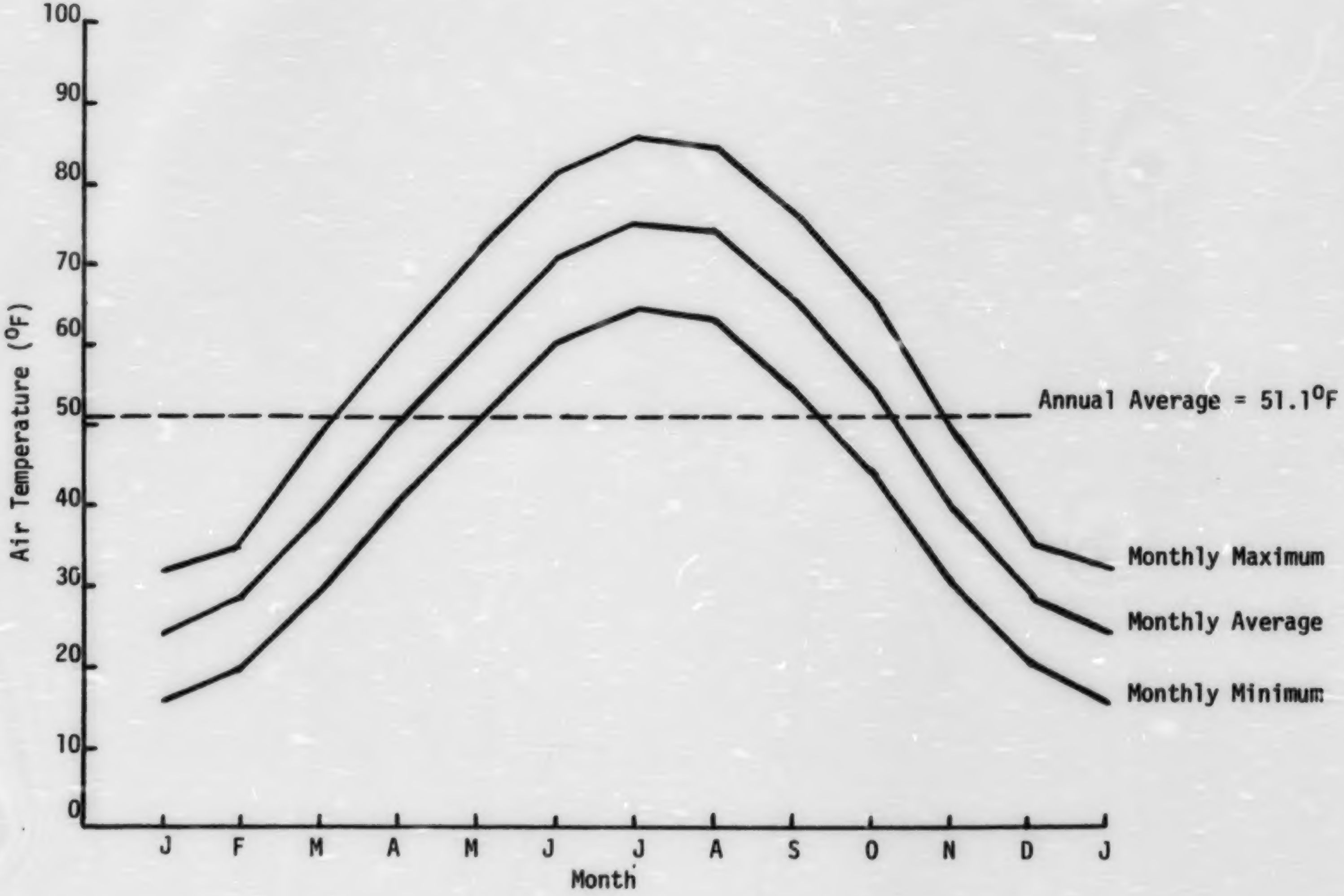


Figure IV-1. Patterns of Variation in Monthly Average, Maximum, and Minimum Temperatures at Peoria Airport Station, 40-Year Data from 1935 to 1974 (National Climatic Center, 1974b)

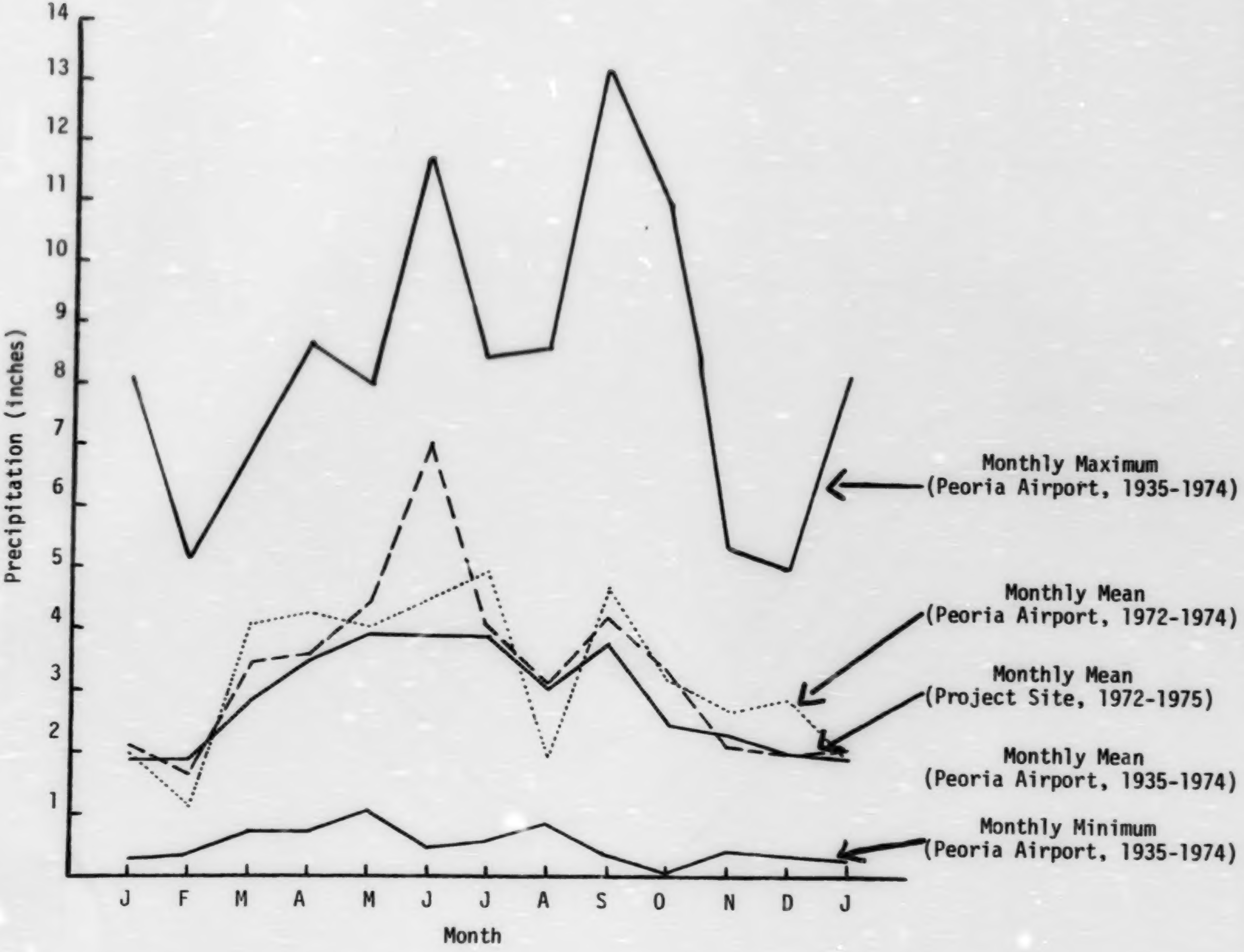


Figure IV-2. Variations in Monthly Mean, Maximum, and Minimum Precipitation at Peoria Airport Station (National Climatic Center, 1974b)

Table IV-1. Predicted 24-Hour Storm Patterns for Fulton County (MSDGC, 1975a)

Inches of Rain for 24-Hour Storm

Recurrence Interval	Hour 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
100 years	.07	.07	.08	.09	.1	.11	.13	.14	.18	.23	.65	3.03	.36	.28	.16	.15	.12	.11	.1	.09	.08	.08	.07	.05
25 years	.035	.046	.046	.046	.058	.058	.081	.092	.138	.173	.58	2.74	.311	.219	.115	.104	.07	.07	.058	.046	.046	.046	.035	.035
5 years	.035	.035	.035	.035	.047	.047	.059	.07	.11	.129	.445	2.13	.246	.176	.094	.082	.059	.059	.047	.035	.035	.035	.00234	.0234
1 year	.02	.02	.02	.025	.03	.03	.04	.05	.07	.09	.29	1.39	.96	.11	.06	.05	.04	.03	.03	.03	.02	.02	.02	.02

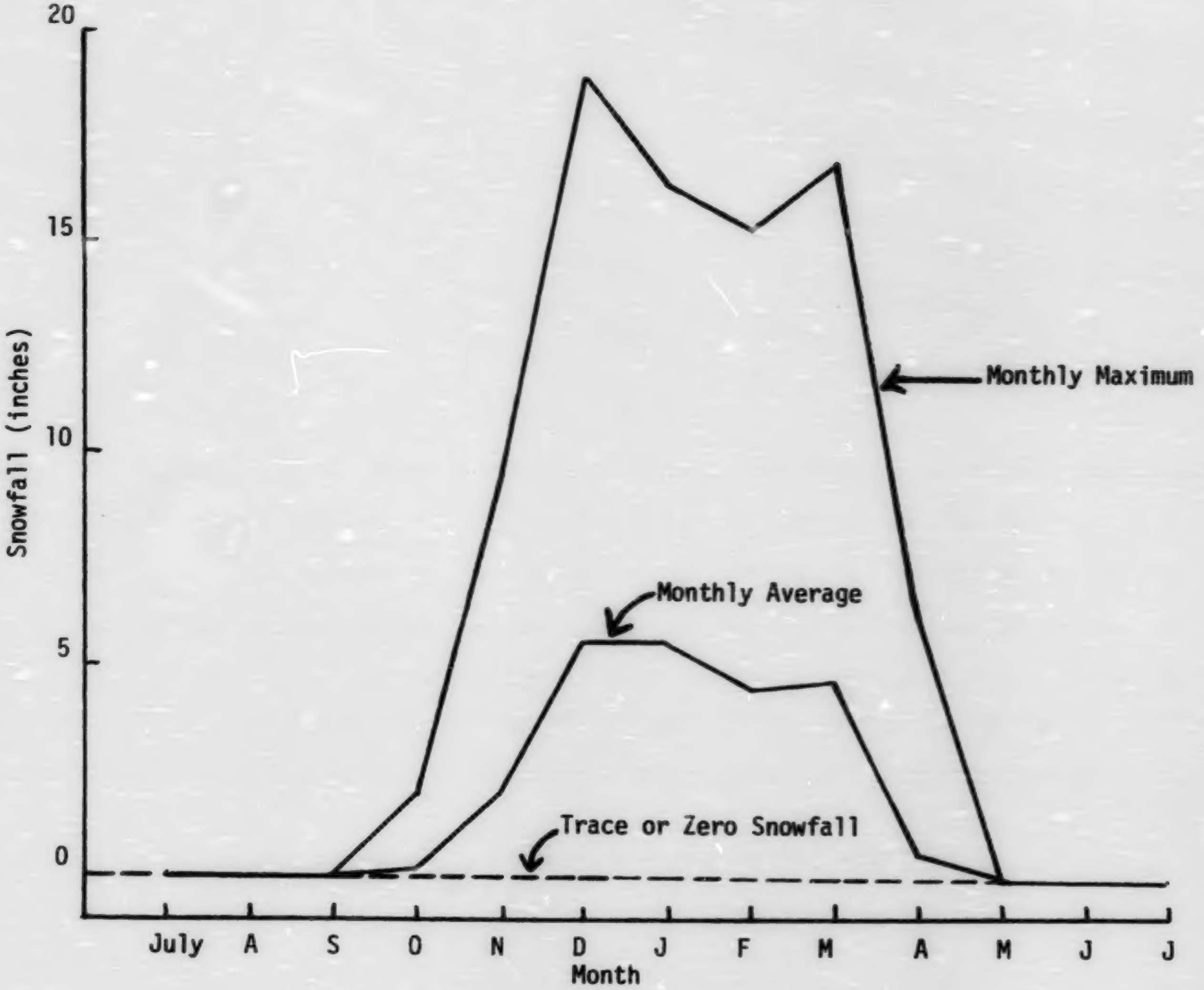


Figure IV-3. Variations in Monthly Mean, Maximum, and Minimum Snowfall, Peoria Airport Station, 40-Year Data from 1935 to 1974 (National Climatic Center, 1974b)

b. Wind vectors - Wind data is recorded for direction and speed. By dividing the number of recorded wind vectors within a given sector of wind direction and interval of wind speed by the total number of observations, the frequency of winds in that vector interval can be established. Normally 16 wind directions 22.5 degrees apart are chosen for this type of analysis, along with four wind speed intervals (0-3, 3.1-6, 6.1-10, and 10.1 mph or higher). The average wind vector frequencies at Greater Peoria Airport between 1964 and 1973 are given in Table IV-2. Calm periods normally occur during 2.83% of the year.

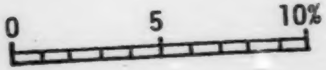
The vector frequencies presented in Table IV-2 were used to construct a wind "rose" as shown in Figure IV-4. The vectors in this figure indicate wind directions and contain four segments, each representing a wind speed interval with the lowest wind speeds beginning at the core of the rose. The frequency of wind in a given wind speed interval and wind direction is proportional to the length of its representative segment. This wind rose indicates that southerly winds prevail in this general area for all wind velocities. Winds from other sectors are rather uniformly distributed. A wind rose representing conditions at the holding basins on the project site was constructed and is shown in Figure IV-5. Data were available for approximately 3 years only; therefore, the level of statistical confidence in this case is not as high. At the project site, there is a strong southerly wind component as there is at Peoria Airport. However, at the site, winds from the southwest and west-northwest sectors are similarly important. The differences between the two wind roses are believed to be due to differences in local terrain.

c. Atmospheric stability - In air pollution studies concerning the dispersion of airborne materials, atmospheric stability, which is a measure of the mixing capacity of the atmosphere, is of major interest. A stable atmposphere has a limited mixing ability and provides little capacity for the dilution of air pollutants. Pasquill introduced a system for the classification of

Table IV-2. Average Annual Frequencies of Wind Vectors in Percentage, Greater Peoria Airport, January 1964 through December 1973 (National Climatic Center, 1974a)

Wind Direction	Wind Speed (mph)				All 4 Wind Speed Intervals for Given Wind Direction
	0-3.0	3.1-6.0	6.1-10.0	≥10.1	
North	0.63	1.80	2.44	1.87	6.74
North-Northeast	0.41	1.04	1.15	0.57	3.17
Northeast	0.38	1.03	1.58	1.14	4.13
East-Northeast	-.45	1.33	1.91	1.27	4.96
East	0.46	1.46	2.26	1.16	5.34
East-Southeast	0.41	1.13	1.41	0.68	3.63
Southeast	0.46	1.47	2.02	1.18	5.13
South-Southeast	0.48	1.86	2.40	2.08	6.82
South	1.33	4.51	7.20	5.44	18.48
South-Southwest	0.58	1.63	1.84	1.35	5.40
Southwest	0.59	1.50	1.92	1.28	5.29
West-Southwest	0.63	1.40	1.61	1.18	4.82
West	0.66	1.55	2.16	2.95	7.33
West-Northwest	0.53	1.44	2.02	3.86	7.85
Northwest	0.44	1.29	2.24	2.43	6.40
North-Northwest	0.41	1.16	1.78	1.16	4.51
All 16 Wind Directions for Given Wind Speed Interval	8.85*	25.60	35.95	29.60	100.00

*Calm periods account for 2.83% annually.



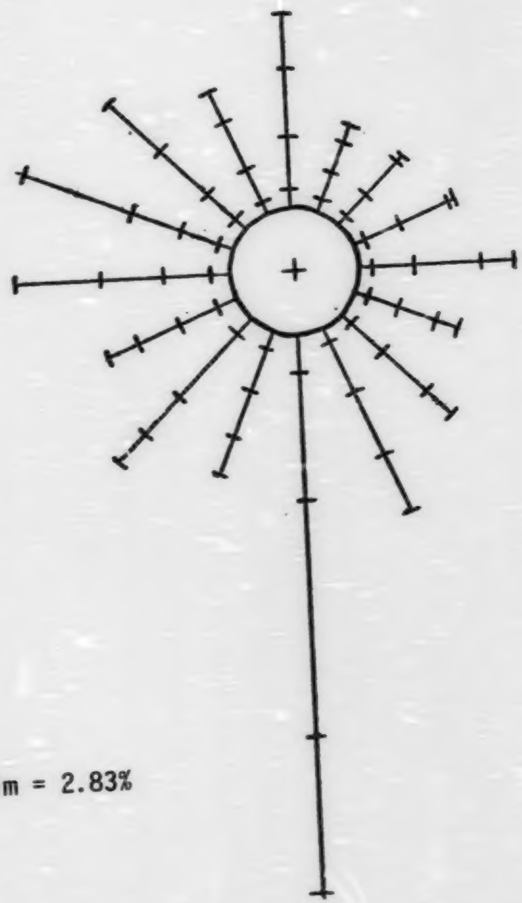


Figure IV-4. Wind Rose at Meteorological Station #14842, Peoria, Illinois, January 1964 through December 1973 (National Climatic Center, 1974a)

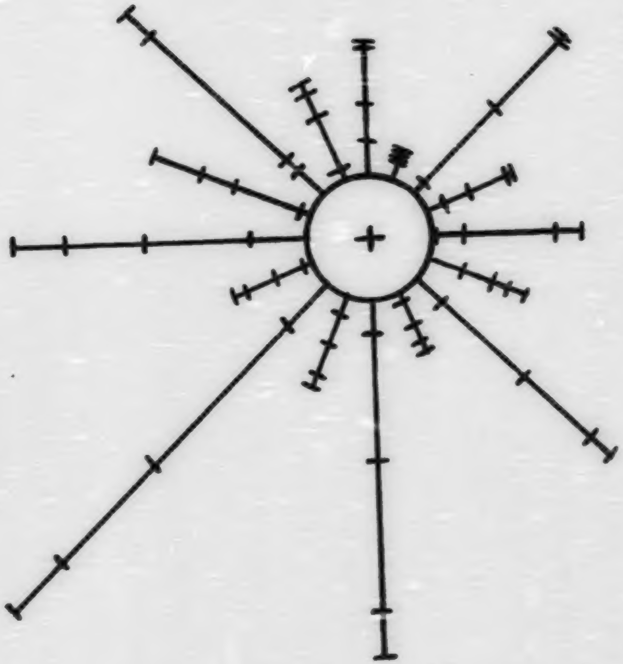


Figure IV-5. Wind Rose at Storage Basins, MSDGC Fulton County Project Site (MSDGC, 1975b)

atmospheric stability (Turner, 1964). Parameters considered in this system include net solar insolation, solar altitude, cloud cover and ceiling height, wind speed, and the presence of urbanization. There are seven stability classes: Class A, extremely unstable; Class B, unstable; Class C, slightly unstable; Class D, neutral; Class E, slightly stable; Class F, stable; and Class G, extremely stable. Based on data collected at the Greater Peoria Airport station, the annual and seasonal percentages of occurrence for each stability class are summarized in Table IV-3. The predominant atmospheric condition in the area is Pasquill Stability Class D, a neutral atmosphere, with an annual frequency of 57.75%, or 211 days per year.

d. Typical weather conditions - Climatic conditions in the Peoria area are summarized in Table IV-4. The annual prevailing wind is southerly with a yearly mean speed of 10.3 mph. Relative humidity is seldom below 50%, ranging between 62 and 83 percent (annual average). The average number of days with heavy fog or visibility equal to or less than 1/4 mile ranges from 1 to 3 days per month and peaks during winter. Nighttime radiational loss is believed to be the major factor contributing to poor visibility. Ground fog normally occurs during the night and at dawn. Periods of low ceiling height and light wind can lead to severe conditions during which air pollutants accumulate at ground level. The annual joint frequency of low ceiling height and light wind is 0.2678% which is equivalent to only 24 hours in a year.

In brief, the most probable weather conditions in the study area are a neutral atmosphere (Pasquill Stability Class D) and southerly winds at 10.2 mph. A calm atmosphere with a mixing height of less than 100 meters and wind speed less than 1 mph represents the worst conditions in terms of air pollution potential. In regard to soil erosion, sedimentation, and water quality problems, the 24-hour, 100-year storm can be justified as the worst condition, resulting in a rainfall of 6.53 inches in 24 hours.

Table IV-3. Atmospheric Stability at the Greater Peoria Airport Station (National Climatic Center, 1974a)

	Pasquill Stability Class						
Period	A Extremely Unstable	B Unstable	C Slightly Unstable	D Neutral	E Slightly Stable	F Stable	G Extremely Stable
SPRING: (March, April, & May)	0.24	3.51	8.97	65.26	11.30	7.95	2.77
SUMMER: (June, July, & August)	1.01	10.53	18.01	38.93	11.36	13.56	6.60
FALL: (September, October, & November)	0.04	2.57	8.81	54.71	14.70	13.76	5.40
WINTER: December, January, & February)	0.01	0.42	5.04	72.38	11.71	8.07	2.38
ANNUAL	0.33	4.28	10.24	57.74	12.26	10.84	4.30

Table IV-4. Summary of Climatic Conditions in the Area of Peoria, Illinois (National Climatic Center, 1974a, 1974b, 1975)

Period		Prevailing Wind		Range of Relative Humidity (%)	Average Number of Days with Heavy Fog or Visibility of 1/4 Mile or Less	Percent of Time Each Year		
		Direction	Speed (mph)			Ceiling Height Equal to or Less than 400 ft.	Light Winds	Joint Frequency of Height and Light Winds
SPRING	March	WNW	12.3	64-81	2	0.37	0.25	0.0116
	April	S	12.3	56-78	1	0.09	0.28	0.0032
	May	S	10.5	57-81	1	0.20	0.79	0.0187
SUMMER	June	S	9.2	56-81	1	0	0.52	0
	July	S	8.0	59-86	1	0	0.93	0
	August	S	7.8	59-87	1	0.12	0.76	0.0102
FALL	September	S	8.8	65-88	1	0.16	0.40	0.0094
	October	S	9.5	58-85	2	0.35	0.70	0.0292
	November	S	11.2	66-83	2	0.54	0.21	0.0137
WINTER	December	S	10.9	73-83	3	1.06	0.39	0.0532
	January	S	11.2	68-78	3	1.03	0.57	0.0739
	February	WNW	11.6	66-77	3	0.58	0.92	0.0447
YEAR		S	10.3	62-83	21	--	--	0.2678
LENGTH OF RECORD (years)		31		15	31	2	2	2

2. General Topography

One end result of the large-scale strip mining operations in Fulton County is an extremely rough topography. Strip mining has left steeply sloping spoil mounds and a number of long, narrow lakes with abruptly sloping shorelines scattered about the project site. These lakes are mostly supplied by groundwater with a slight contribution from surface runoff. Uneven settling of unconsolidated and clayey soils within the mined sections has produced an almost undulating surface. In addition, the project area is covered with rocks and potholes. The application fields have been prepared for agricultural use by levelling and grading, filling potholes and removing rocks. As a result, the application fields themselves have a level to gently sloping topography.

Features of terrain have some influence on microclimate, including modification of the wind flow pattern. Formation of lakes and reservoirs resulting from mining activities in the past probably have changed the amount and distribution of thermal energy at the site. Availability of moisture from lake or reservoir evaporation, coupled with nighttime loss of thermal energy from the ground surface by radiation, may encourage formation of ground fogs which limit the mixing ability of the surface air layer. If fogging persists beyond mid-morning hours or extends throughout the day, airborne contaminants such as malodorants may accumulate near the ground or in depressions.

The capacity of storm runoff to carry suspended solids such as silt or spoil fines may have been increased by the steepened slopes resulting from coal stripping and piled, abandoned spoil. This is evidenced by several spoil downwashes on the project site. The leveling and grading accomplished for site preparation should have significantly reduced the erosion problem. Site areas not developed as sludge application fields may continue to erode, causing water quality problems. The most significant problem is the leachate from unearthed black shale which is high in soluble minerals (including cadmium).

B. GEOLOGY AND SOILS

Environmental impacts such as erosion or groundwater contamination, and socio-economic factors such as land development potential, will depend to a great degree upon the geological and soil characteristics. This section contains a discussion of past and present geological conditions and a description of soil characteristics in the vicinity of Fulton County.

1. Geological Characteristics

The land surface is covered with unconsolidated soil deposits in this general area which nearly obscure the bedrock except near the valleys of major drainage channels. A brief discussion of the bedrock and pleistocene stratigraphy is presented in this section, concluding in a description of the characteristics of mine spoils.

Outcrops of bedrock reveal that the geological formation consists of shales and sandstones, containing several strata of coal and limestone beds. Figure IV-6 shows a typical stratigraphic profile. A soft gray shale known as Canton Shale, approximately 40 to 60 feet thick, lies immediately beneath the surface soil deposits. This shale is underlain by 1 to 2 feet of gray, fossiliferous limestone known as Saint David Limestone. Beneath this stratum are 4 to 6 feet of black shale, which merges into a high-quality coal designated as No. 5 or Springfield coal. This coal seam has a thickness of 4 1/2 to 5 feet and is located near elevation 580. The relatively shallow depth and high quality of this coal has led to considerable strip and shaft mining throughout the general area. The coal is underlain by soft clay to shale and several other thin strata of limestone and shale. These layers have a total thickness of approximately 5 to 8 feet.

The bedrock surface is covered by a 30 to 50-foot mantle of glacial drift or drift-related deposits. The bottom layer is composed of a silty clay to clayey silt matrix resulting from glacial till during the Illinois Glacial Era. Illinoisan glacial till is topped by a windblown silt material known as loess, which is approximately 20 to 30 feet thick. Past coal

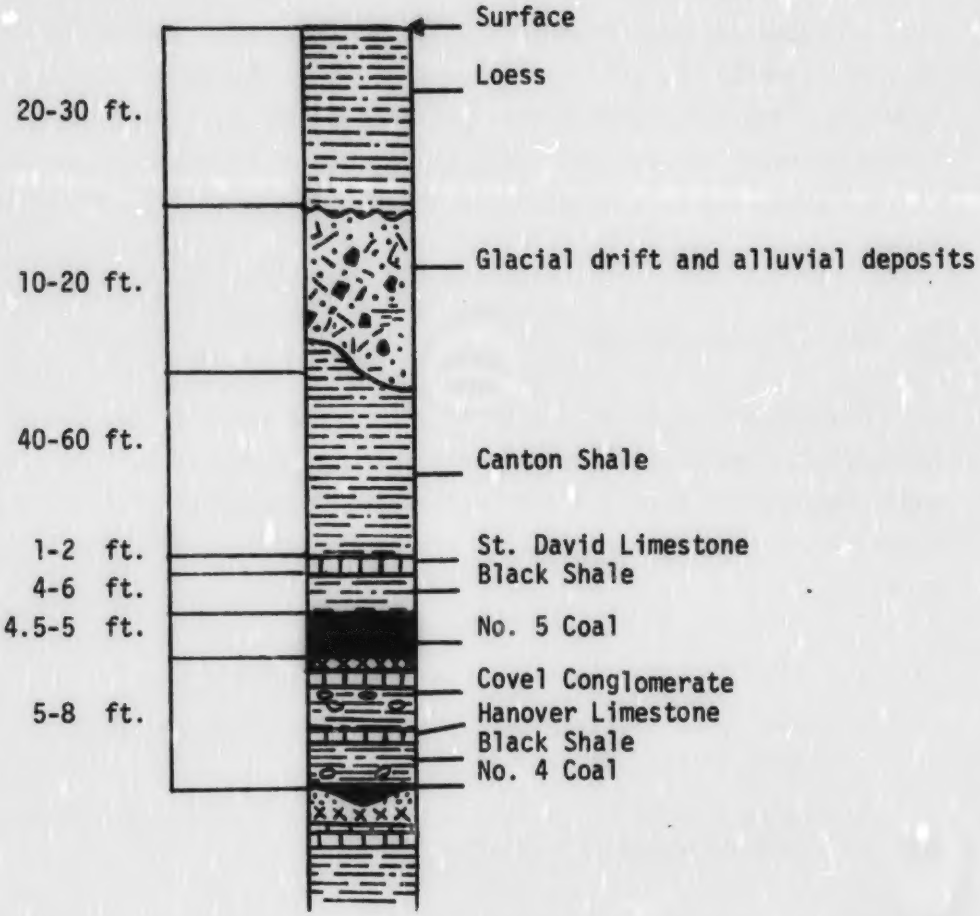

Surface
Loess
20-30 ft.
Glacial drift and alluvial deposits
10-20 ft.
40-60 ft.
Canton Shale
1-2 ft.
St. David Limestone
4-6 ft.
Black Shale
4.5-5 ft.
No. 5 Coal
Covel Conglomerate
5-8 ft.
Hanover Limestone
Black Shale
No. 4 Coal

Figure IV-6. Typical Stratigraphic Profile in the Project Area (A&H Engineering Corporation, 1971)

mining operations have modified this stratigraphic profile. The uppermost bedrock strata and the unconsolidated sediments have been removed and remolded into a generally similar but locally variable soil mass (A&H Engineering Corporation, 1971).

The characteristics of the calcareous mine spoil material have been analyzed and are presented in Table IV-5. Clay species in the clay fraction of the soil were investigated by the potash content, surface area, and X-ray diffraction patterns of the soil particles. Illite is the dominant mineral and accounts for 54% of the total clay. Kaolinite was estimated at 27%, chlorite at 8%, and vermiculite at 11% of the total.

2. Soil Characteristics

A study of the project site to identify areas with basically similar soil and groundwater characteristics was conducted by L. T. Hooper under subcontract with the A&H Engineering Corporation (Hooper, 1971). According to Hooper, the project site can be divided into three basic areas:

- Area 1 -- completely strip-mined land
- Area 2 -- virgin or placeland with a cover of loess over glacial till
- Area 3 -- alluvial land within major stream beds, affected by mining activities.

The spatial distribution of these soil areas is presented in Figure IV-7.

During surface mining operations, the overburden soils and cap rock in Area 1 were removed from the entire area to obtain coal. Therefore, the subsurface of Area 1 consists of a heterogeneous landfill which is composed of cohesive fine-grained soils with pockets and discontinuous zones of boulder-size rock. These rearranged and redistributed overburden soils are rather impervious. Numerous depressions were created, most of which have no drainage outlet. Large lakes maintain a nearly

Table IV-5. Selected Characteristics of the Fulton County Calcareous Mine Spoil Material (MSDGC, 1974)

Spoil material	
pH	7.8
E.C. μmhos/cm	0.46
1/3 bar water, %	26.72
15 bar water, %	12.49
Cation exchange capacity, meq/100 g	14.8
Ammonium fixation capacity, meq/100 g	5.2
Sand content, %	8
Silt content, %	64
Clay content, %	28
Clay fraction only	
Illite, %	54
Kaolinite, %	27
Chlorite, %	8
Vermiculite, %	11
Surface area, m^2/g	138
K_2O, %	4.47
Na_2O, %	0.82
MgO, %	2.29
CaO, %	1.15

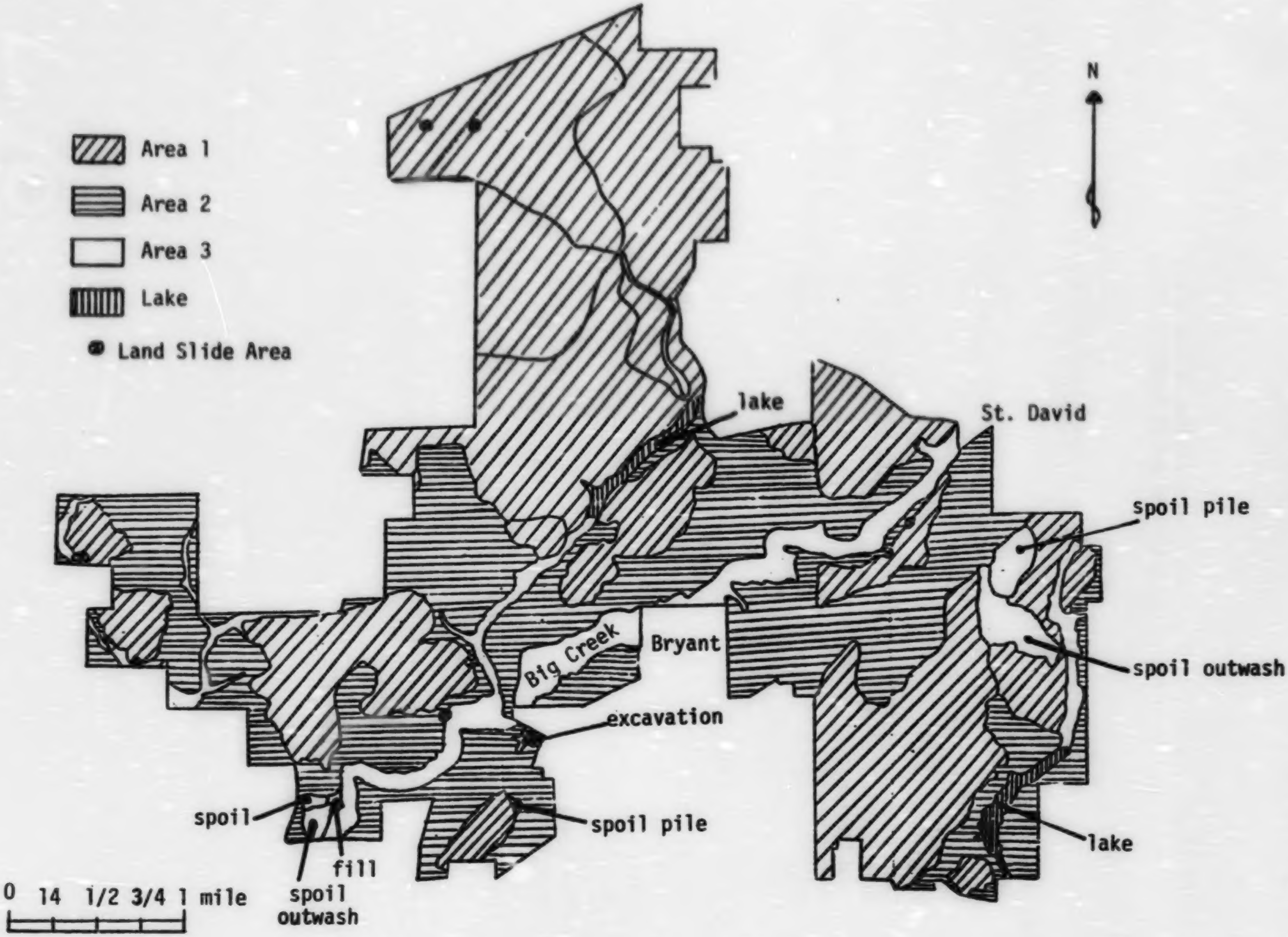

N
Area 1
Area 2
Area 3
Lake
Land Slide Area
lake
St. David
spoil pile
spoil outwash
Big Creek
Bryant
excavation
spoil
fill
spoil outwash
spoil pile
lake
0 14 1/2 3/4 1 mile

Figure IV-7. Spatial Distribution of Soil Areas (Hooper, 1971)

uniform level which is believed to coincide with the groundwater table. Mining activities have resulted in slightly different features in parts of Area 1. A sub-classification of Area 1 and its description can be found in the Subsurface Investigation and Evaluation - Final Report (Hooper, 1971).

Area 2 is the area in which no strip mining activities have been undertaken. Approximately 4 to 8 feet of loess, which is comprised of 50% clay and 50% silt-sized particles, covers the glacial soils. These materials are essentially impervious, but are subject to erosion if exposed on slopes steeper than 1:5. A groundwater table at a depth of approximately 15 feet is normal throughout the area with the exception of slopes leading down to stream valleys. It is known that much of Area 2 has been mined underground by tunneling methods (Hooper, 1971).

Area 3 consists of alluvial soils within major stream beds, and defines most of the continuous drainage channels. These soils are relatively impervious to percolation water, but are moderately permeable to horizontal flow. A high groundwater table is normal here.

Based on field pumping tests, laboratory tests, and analysis of existing groundwater conditions, the permeability of the overall mass of mine spoil is estimated to be in the range of 10^{-3} to 10^{-5} centimeters per second (cm/sec). The vertical permeability of soils was estimated by laboratory tests to be from 10^{-5} to 10^{-9} cm/sec. According to Casagrande's classification of soils by permeability, these soils are impervious, non-draining or poorly draining (Casagrande, 1948). However, some zones or layers may consist of broken shale and sandstone slabs or blocks arranged in a way that provides a rapid path for water, and may possess a permeability as high as 10^{-1} cm/sec (A&H Engineering Corporation, 1971).

There are no published Soil Conservation Service soil surveys available for Fulton County. However, the Fulton County Soil Conservation Agent at Lewistown provided highly useful information concerning the agricultural capability of local soils (see Section F. 3. of this chapter).

C. HYDROLOGY AND WATER QUALITY

This section describes the hydrological and water quality characteristics of the project area. The purposes of this review are to define local hydrological patterns, establish baseline water quality information, and define their interrelationships. Moreover, the background quality of ground and surface waters and their respective flows will determine their vulnerability to project impacts.

1. Surface Water Hydrology

The project site is located within the Illinois River basin. Most of the surface water is drained by Big Creek and Slug Run, a branch of Big Creek, to Spoon River, a tributary of the Illinois River. The tributaries associated with the project site, on a regional scale, are shown in Figure IV-8. The flows of Big Creek and Spoon River have been monitored at three USGS gage stations. Two stations are located on Big Creek at St. David and near Bryant, and the third on the Sppon River at Seville. The daily average, maximum, and minimum discharges at these stations in 1972 and 1973 are shown in Table IV-6. (The detailed drainage pattern near the project site is depicted in Figure IV-9, page IV-24.)

Table IV-6. Daily Discharges at USGS Gage Stations (USGS, 1972 and 1973)

	1972 Daily Discharge (cfs)			1973 Daily Discharge (cfs)		
	Mean	Maximum	Minimum	Mean	Maximum	Minimum
Big Creek at St. David, Illinois USGS Station 05570350	16.9	137	1.9	39.4	700	7.6
Big Creek near Bryant, Illinois USGS Station 05570370	28.3	259	6.7	56.4	803	11.0
Spoon River at Seville, Illinois USGS Station 05570000	625.0	5150	37.0	--	--	--

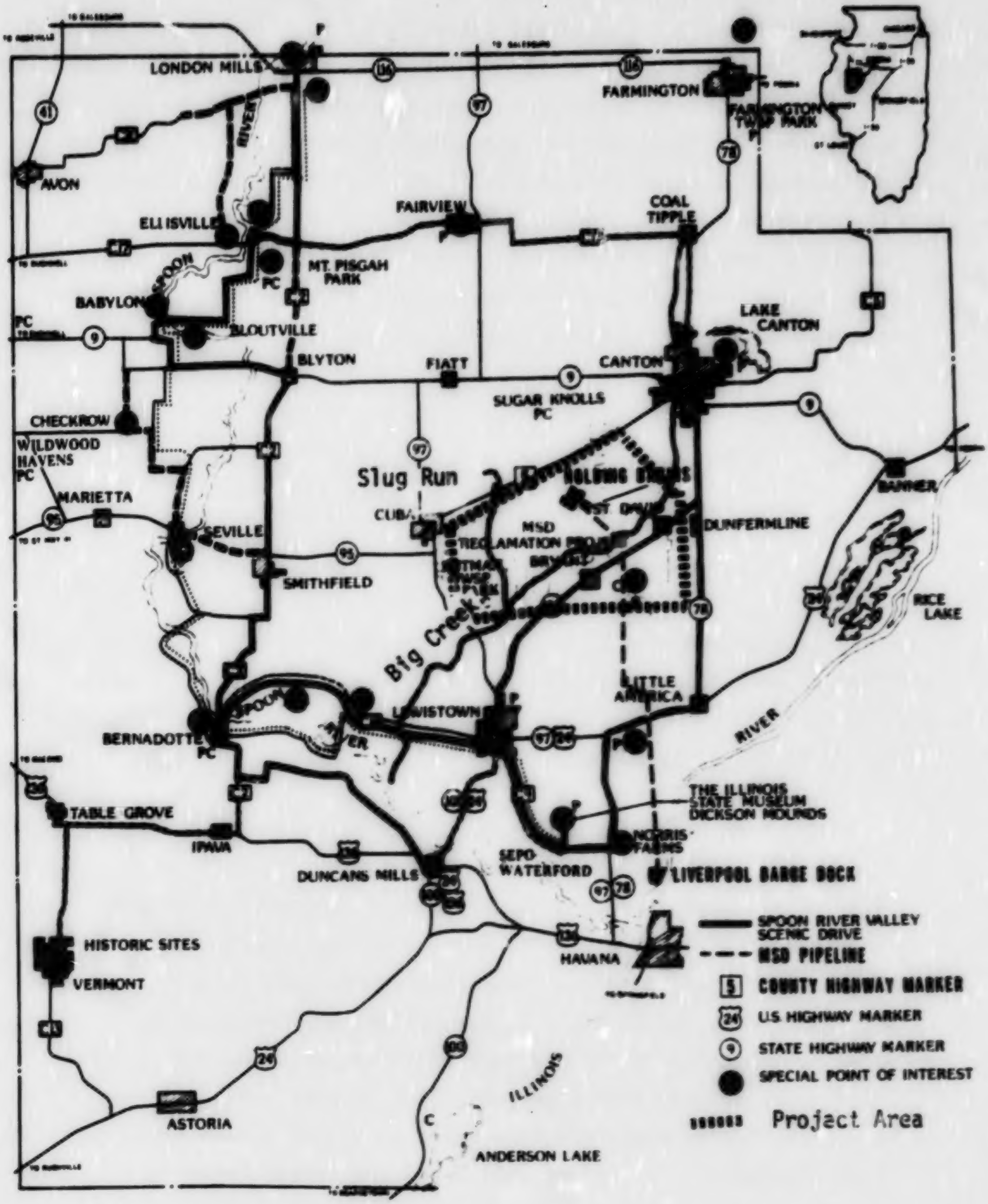

LONDON MILLS
FARMINGTON
FARMINGTON TWSP PARK
AVON
ELLISVILLE
FAIRVIEW
COAL TIPPLE
MT. PISGAH PARK
BABYLON
BLOUTVILLE
LAKE CANTON
BLYTON
FIATT
CANTON
SUGAR KNOLLS PC
CHECKROW
WILDWOOD HAVENS PC
MARIETTA
Slug Run
CUBA
MSD RECLAMATION PROJECT
ST DAVID
DUNFERMLINE
BANNER
SEVILLE
SMITHFIELD
RICE LAKE
Big Creek
LITTLE AMERICA
LEWISTOWN
BERNADOTTE
PC
SPOON RIVER
RIVER
TABLE GROVE
IPAVA
THE ILLINOIS STATE MUSEUM DICKSON MOUNDS
NORRIS FARMS
SEPO
WATERFORD
DUNCANS MILLS
LIVERPOOL BARGE DOCK
HISTORIC SITES
VERMONT
HAVANA
ASTORIA
ILLINOIS
ANDERSON LAKE
SPOON RIVER VALLEY SCENIC DRIVE
MSD PIPELINE
5 COUNTY HIGHWAY MARKER
24 U.S. HIGHWAY MARKER
9 STATE HIGHWAY MARKER
SPECIAL POINT OF INTEREST
Project Area

Figure IV-8. Illinois River and Tributories associated with Project Site.

Based on a soil permeability of 10^{-5} cm/sec, as discussed in Section IV.B., the vertical infiltration rate ranges from 1.2×10^{-6} inches per hour, for a rainfall intensity of 0.01 inches per hour, to 3.54×10^{-4} inches per hour for an intensity of 3 inches per hour. The latter is equivalent to the peak hourly rainfall from a 24-hour, 100-year storm. It is clear that the amount of rainwater infiltrating the soil surface is relatively insignificant when compared to surface runoff. In other words, poor soil drainage forces rain water to be discharged to creeks or streams in surface runoff. Assuming no percolation through the soil and no evapotranspiration by plants, the runoff volume of a one-acre drainage surface is about:

- 23,700 cubic feet for a 24-hour, 100-year storm
- 19,000 cubic feet for a 24-hour, 25-year storm
- 14,900 cubic feet for a 24-hour, 5-year storm
- 9,000 cubic feet for a 24-hour, 1-year storm.

Flood hazards are generally confined to the flood plains, which are outlined as Area 3 in Figure IV-7 (page IV-18).

2. Groundwater Hydrology

Migration or drainage of groundwater is much more difficult to define than for surface water. With the aid of well-water elevations and river water levels, the groundwater flow in the general area has been interpreted qualitatively. The water elevations in 22 wells within and around the project site have been observed monthly by MSDGC personnel. After some data reduction, all observations are expressed as an average value, accompanied by its standard deviation and range of variation throughout the observation periods. The results are summarized in Table IV-7. (All water elevations are based on USGS mean sea level with the 1929 adjustment.) Utilizing well water and stream water levels, the pattern of groundwater flow can be established by the "streamline" method. The pattern is displayed in Figure IV-9.

Table IV-7. Elevations of Well Water (MSDGC 1972 a through 1975 g)

Well	W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12	W13	W14
Mean Elevation (ft. msl)	--	--	--	--	--	617.9	608.8	622.2	593.6	621.3	624.5	628.1	601.6	638.4
Standard Deviation (ft.)	--	--	--	--	--	7.8	2.0	3.7	2.1	6.4	1.4	1.7	0.9	1.5
Range of Variation (ft.)	--	--	--	--	--	24.0	6.0	9.9	6.0	20.2	4.0	4.0	3.0	5.0
Observations	0	0	0	0	0	18	20	11	18	18	9	19	13	16

Well	W15	W16	W17	W18	W19	W20	W21	W22	W23	W24	W25	W26	W27
Mean Elevation (ft. msl)	656.7	614.8	625.3	632.0	608.0	600.0	572.0	571.4	601.2	675.7	647.7	659.8	673.8
Standard Deviation (ft.)	0.4	0.6	3.7	1.2	16.2	--	--	1.3	3.2	2.4	9.3	1.9	6.2
Range of Variation (ft.)	0.7	2.0	12.0	3.3	61.1	--	--	4.0	10.0	8.0	25.0	4.0	21.0
Observations	4	10	16	5	14	1	1	10	20	21	20	7	19

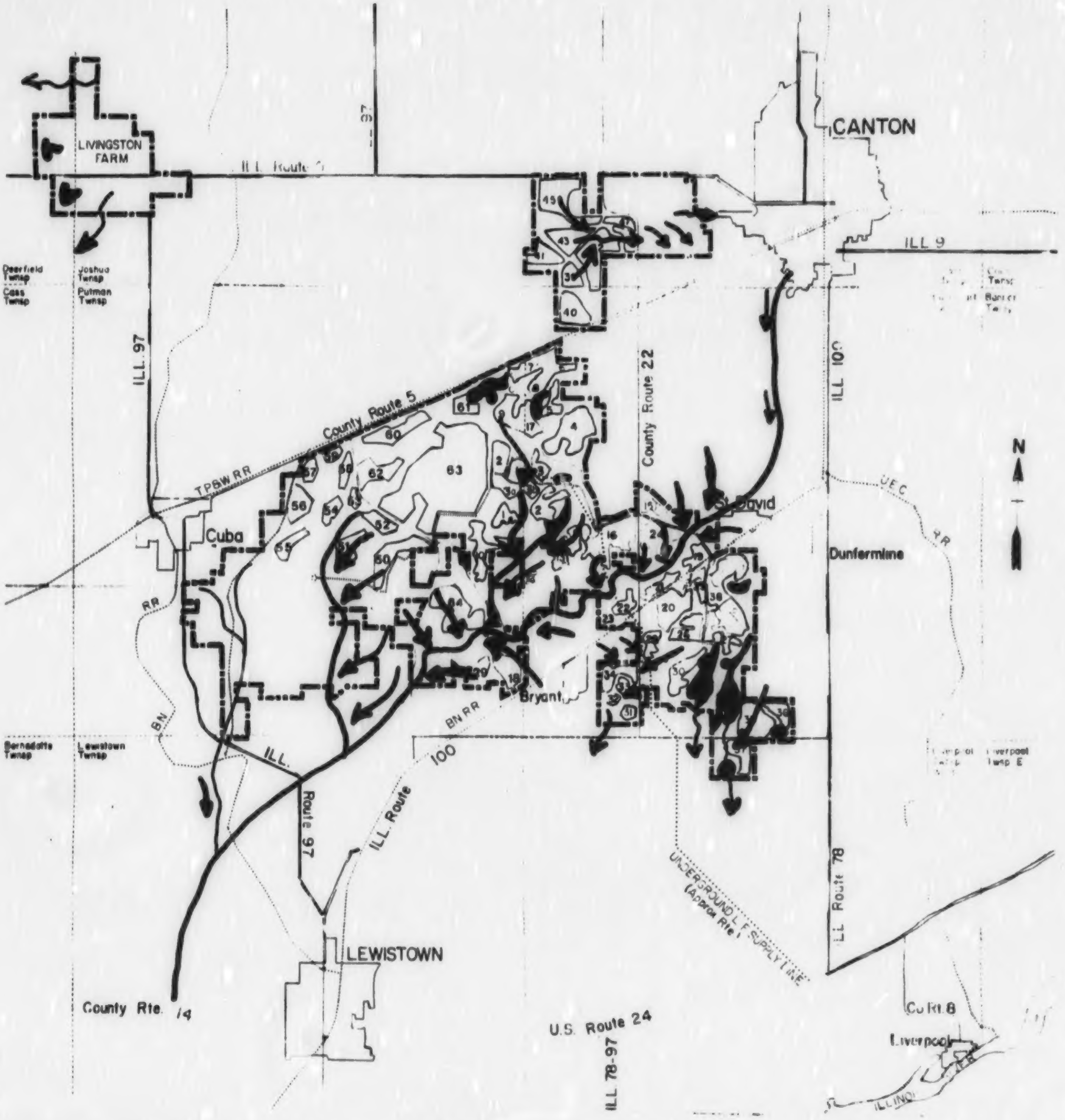

LIVINGSTON FARM
ILL. Route 9
37
CANTON
ILL 9
Deerfield Twnsp
Joshua Twnsp
Cass Twnsp
Putman Twnsp
ILL. 97
County Route 5
TP&W RR
Cuba
RR
County Route 22
St. David
Dunfermline
ILL 100
UEC RR
N
45
43
39
40
61
17
4
60
63
57
58
62
2
56
54
53
52
55
51
50
16
20
38
64
23
25
30
29
18
31
Bryant
BN RR
BN
Bernadotte Twnsp
Lewistown Twnsp
ILL.
Route 97
100
ILL. Route
Liverpool Twnsp E
UNDERGROUND LF SUPPLY LINE (Approx Rte)
ILL Route 78
LEWISTOWN
County Rte. 14
U.S. Route 24
ILL 78-97
Co Rt 8
Liverpool
ILLINOIS

Figure IV-9. Pattern of Groundwater Flow (MSDGC 1972a through 1975g)

The interactions between groundwater and surface water systems cannot be attributed solely to soil percolation or trans-migration because soils in this area are relatively impermeable. Therefore, surface water flow is generally derived from upstream tributary flow, storm runoff, and snow melt. Paths of rapid flow between ground and surface waters may furnish the mechanism for groundwater depletion. Since there are a number of stable surface water impoundments in the area, it is likely that groundwater replenishes the surface water system.

3. Water Quality

To assess possible impact on water quality from project operations, surface and groundwater quality prior to project implementation must be established. Using 1971 as the baseline year, stream water quality at monitoring stations S1, S2, and S3 (see Figure IV-a) is summarized in Table IV-8. These measurements must be compared to standards for the State of Illinois, which are presented in Chapter II. The 1971 pH values and the chloride (Cl), cadmium (Cd), chromium (Cr), manganese (Mn), mercury (Hg), nickel (Ni), and zinc (Zn) concentrations were generally in conformance with water quality standards. Average concentrations of sulfate ions (SO_4), copper (Cu), and lead (Pb) were within or marginally close to standards. However, these standards were violated occasionally, as evidenced by the 1971 maximum concentrations which were all higher than related standards. Ammonia nitrogen (NH_3-N), iron (Fe), and fecal coliform concentrations violated standards on numerous occasions, indicating pollution in Big Creek.

Stations S1 and S2 on Big Creek constitute an upstream-downstream pair relative to the project site. The water quality at upstream station S1 might be affected to some extent by the treated sewage effluent from the Canton sewage treatment plant. Generally, the stream at station S1 was lower in quality than at the downstream station S2 with respect to Cl, SO_4, NH_3-N, Cu, and fecal coliforms. This indicates that cleansing and dilution occurred along the approximately 6.5-mile stream reach

Table IV-8. Surface Water Quality in 1971 (MSDGC, 1971)

Parameter and Unit		Monitoring Station		
		S1	S2	S3
pH	mean	7.9	8.1	8.0
	max.	8.8	8.7	8.3
	min.	7.3	7.1	7.5
Cl^- (mg/l)	mean	53	28	10
	max.	120	72	15
	min.	24	4	6
SO_4^{-2} (mg/l)	mean	389	381	606
	max.	1,250	879	743
	min.	120	80	424
NH_3-N (mg/l)	mean	2.6	1.8	0.4
	max.	8.1	6.6	0.7
	min.	0.3	0.1	0.1
Cd (mg/l)	mean	0	0	0
	max.	0	0.06	0.04
	min.	0	0	0
Cu (mg/l)	mean	0.02	0.02	0.01
	max.	0.13	0.06	0.03
	min.	0	0	0
Cr (mg/l)	mean	0	0.02	0.02
	max.	0.18	0.28	0.12
	min.	0	0	0
Fe (mg/l)	mean	1.5	1.3	0.3
	max.	4.8	4.5	0.6
	min.	0	0.1	0.1
Pb (mg/l)	mean	0.05	0.09	0.08
	max.	0.2	0.28	0.2
	min.	0	0	0
Mn (mg/l)	mean	0.7	0.86	0.47
	max.	0.98	1.31	0.96
	min.	0.06	0.60	0.24
Hg (mg/l)	mean	0.05	0	0.2
	max.	0.2	0.2	0.6
	min.	0	0	0
Ni (mg/l)	mean	0	0	0
	max.	0.35	0.33	0.31
	min.	0	0	0
Zn (mg/l)	mean	0	0	0
	max.	0.2	0.2	0
	min.	0	0	0
Fecal Coliforms (1/100 ml)	mean	7,500	1,700	920
	max.	34,000	3,800	4,000
	min.	270	20	80

between the two stations. Levels of cadmium, iron, nickel, and zinc remained relatively constant at both stations. Surface runoff and leachates originating in the strip-mined area along this segment of Big Creek might be the cause of increased levels of chromium, lead and manganese in the downstream direction. However, lack of detailed data prevents the specific identification of the source.

Groundwater samples were collected from a number of wells and one spring (see Figure IV-9, page IV-24).The measured ranges of all groundwater quality parameters reported in 1971 and 1972, prior to project operation, are presented in Table IV-9. In this table, the well responsible for the maximum reading of a given parameter is designated by parentheses. Wells W2, W4, W9, W11, W12, and W13 indicated high degrees of contamination. Variations in concentrations of nitrite and nitrate nitrogen (NO_2+NO_3-N) and ammonia nitrogen (NH_3-N) at all monitoring stations are summarized in Table IV-10 for 1972.

In earlier years the U.S. Department of the Interior conducted a survey of water quality from wells and infiltration galleries in more than 17 study areas throughout the United States. The range in quality of groundwater used for water supply is summarized in Table IV-9 (Durfer and Becker, 1965). Comparison of the baseline groundwater quality in the project area with that from the Department of the Interior study indicates that concentrations of Cr, Cu, Fe, Pb, Mn, and Ni in the project area were within the range found elsewhere in the United States; the ranges of pH and zinc concentration were close to the national values. Concentrations of Cl, SO_4, Ca, Mg and Na were higher than those found nationwide, indicating that dissolved solids or salt concentrations were relatively high in the project area.

The U.S. recommended maximum level of nitrite and nitrate nitrogen for drinking water is 10 mg/l as nitrogen (U.S. Department of Public Health Service, 1962 and 1969). If all ammonia nitrogen were oxidized to nitrite or nitrate, the range of nitrite and nitrate nitrogen concentrations in the project area would fall between zero and 5.21 mg/l. This range falls within the lower one-third of the national range of 0 to 17 mg/l as reported by Durfer and Becker (1965). The maximum nitrite and nitrate concentration

Table IV-9. Range of Various Water Quality Parameters in Well Water, 1971 and 1972; and U.S. Averages (MSDGC, 1972a through 1975g; Durfer and Becker, 1965)

Parameter and Unit		1971	1972	Water Used for Water Supply (U.S. average)
pH		6.6-9.0	6.5-9.2	6.7-8.7
Total P	mg/l	0.6.0 (W9)	0 - 0.054 (W2)	--
Cl^-	mg/l	2-500 (W4)	2-488 (W4)	2.0-92
SO_4 =	mg/l	1-500 (W4)	3-1,812 (W14)	0.8-572
Alkalinity ($CaCO_3$)	mg/l	4-1,650 (W11)	100-1,000 (W11)	--
Conductivity	µmho	90-1,050 (W17)	200-4,000 (W4)	108-1,660
Al	mg/l	--	--	2.9-83
Ca	mg/l	33-495 (W12)	38.5-883 (W1)	3.2-121
Cd	mg/l	0-0.1 (W6)	0-0.22 (W2)	--
Cr	mg/l	0-0.39 (W6)	0-0.05 (W13; W18)	ND-1.1
Cu	mg/l	0-0.5 (W2)	0-1.82 (W2)	<0.8-15
Fe	mg/l	0-118.7 (W9)	0-182.6 (W13)	1.1-6,600
Pb	mg/l	0-1.0 (W19)	0-2.2 (W2)	ND-38
Mg	mg/l	21-390 (W12)	23 - 410 (W14)	0.3-120
Mn	mg/l	0-12.7 (W9)	0-8.3 (W12)	ND-340
Hg	mg/ml	0-20 (W19)	0-2.8 (W7)	--
Ni	mg/l	0-0.42 (W10)	0-0.3	ND-<15
K	mg/l	0.1-24.9 (W4)	0-19.4 (W4)	0.4-30
Na	mg/l	11.7-310 (W8)	7-646 (W11)	6.1-129
Zn	mg/l	0-390 (W12)	0-140 (W10)	ND-<470
Fecal Coliforms	1/100 ml	0-<100	0-120 (W7)	--

ND = not detected.

Table IV-10. Levels of Nitrite and Nitrate Nitrogen and Ammonia Nitrogen in Well Waters in 1972 (MSDGC, 1972a through 1975g)

	NO_2+NO_3-N (mg/l)			NH_3-N (mg/l)		
Well	Mean	Max.	Min.	Mean	Max.	Min.
W1	0.03	0.11	0	0.40	0.70	0
W2	0.03	0.11	0	0.80	4.10	0
W4	0.29	1.51	0	1.1	1.9	0
W5	0.04	0.27	0	0.2	0.6	0
W7	0.16	0.28	0.04	0.5	1.1	0.1
W8	0.01	0.05	0	1.8	4.3	0
W9	0.02	0.09	0	1.0	1.7	0
W10	0.02	0.09	0	0.8	1.6	0.4
W11	0	0.02	0	1.8	2.1	1.4
W12	0.03	0.13	0	0.8	1.3	0.2
W13	0.08	0.21	0	0.6	0.8	0.3
W14	0.01	0.07	0	0.6	1.3	0.1
W15	0.06	0.28	0	1.1	1.9	0.3
W17	0.81	2.50	0	0.5	2.2	0.1
W18	0.03	0.11	0	1.8	2.7	1.3
W19	0.03	0.13	0	0.99	2.0	0.0

of 5.21 mg/l, recorded at well W4 in the community of Cuba, was well within the recommended drinking water standard. Apparently, the baseline quality of groundwater in the area of the project, was compatible with use for public water supply. However, the high overall concentration of dissolved minerals, approximately three times the U.S. standard of 500 ppm, could necessitate extensive treatment.

D. BIOLOGY AND ECOSYSTEMS

The following discussion of biology and ecosystems is divided into two sections: fish and wildlife, and natural vegetation. Within each of these are discussed major species, both past and present, and the rare and endangered species possibly inhabiting the project area.

1. Fish and Wildlife

Fish abound in most of the local lakes, and are the most numerous vertebrates in the study area. The predominant fish are bluegill, green and redear sunfish, black crappie, yellow and black bullheads, large-mouth bass, and catfish.

A great diversity of wildlife currently inhabits the project area. Turtles, frogs, water insects, and crustaceans are abundant in Lake Evelyn. There are also some black snakes and signs of beaver activity. The steep-sided lakes formed by strip mining have fewer crustaceans and water insects, but muskrats and frogs are abundant. Land animals include deer, fox, raccoon, skunk, opossum, rabbit, coyote, badger, groundhog, and weasel. Water fowl include ducks, geese (especially the giant Canada goose), swans and an occasional great blue heron. Other birds include crows, hawks, warblers, robins, starlings, sparrows, red-winged blackbirds, bluejays, and finches.

Within historic times, other animals have populated Fulton County. These prairie animals included populations of elk, buffalo, trumpeter swans, sandhill cranes, and the prairie chicken, as well as large predators like the cougar, bear, and wolf. Big Bluestem, a project aimed at recreating a native prairie on part of the MSDGC property (the 2,972-acre former Gale property, see Figure IV-13, page IV-60), is planning to create habitat opportunities for a number of original prairie animals.

Six rare and endangered animal species are listed for the region containing Illinois. Fish species are the longjaw cisco and the blue pike. Endangered birds are the arctic peregrine falcon and Kirtland's warbler, and mammals are the Indiana bat and the eastern timber wolf.

However, the probability of any of these species being present in the project area is extremely remote, and should therefore not present a problem (Smith, 1976, personal communication).

2. Natural Vegetation

The two types of vegetation in the project area consist of cultivated monocultures (predominately corn) in the sludge application fields, and the area's natural vegetation. The following is a discussion of this natural vegetation and the locally rare and endangered plant species which might occur.

The predominant grasses are brome, alfalfa, and reed canary grass. Trees are those generally propagated by wind-blown seeds, including elm, cottonwood, and willow.

Most of the lakes in the project area were formed from the end cuts of strip mining operations, and have steeply sloping sides and a small littoral zone. This zone supports some growth of Chara and Nitella. Diatoms are the predominant planktonic species. No cattails or reeds are present.

A few lakes have gently sloping sides and a relatively large littoral zone. These lakes have an abundance of lake cattails and reeds. Diatoms and lesser amounts of green algae are the major planktonic species. Submerged aquatic vegetation includes stoneworts, Chara, Nitella, Elodea, Vallesenaria, and some of the Potomegetons. Considerable numbers of currant, raspberry, and blackberry bushes grow along the banks.

There are three endangered plant species which probably exist in the project area. (Federal Register, July 1, 1975.) One, an endangered woodland species, is Aster chasei, a woodland aster. Two endangered prairie species are Lespedeza leptostachya, a bush clover found on dry prairie, and Petalostemum foliosum, a prairie clover found near riverbanks.

E. POPULATION AND ECONOMICS

This section is a description and interpretation of the baseline data needed for the assessment of the socio-economic and land use impacts of the project. What is presented here is a selective representation of a broad data collection effort and contains only those data which are relevant to the prediction of impacts. The two main topics discussed in the section are demographic and economic characteristics.

1. Demographic Characteristics

Population will be a major factor in determining the types of land use for which there will be a demand in the project area. The following paragraphs discuss historic and present demographic trends in Fulton County, and give population projections developed from analysis of trends. The section concludes with a discussion of family income in the county.

a. Population trends - Table IV-11 shows historic population trends in Fulton County. The county's population decreased from approximately 50,000 persons in 1910 to about 42,000 in 1970. Slight increases in the populations of Canton, Lewistown and Farmington slowed the decline in total population to 6.1% between 1940 and 1970. However, an increase from 41,900 in April 1970 to 42,400 in July 1974 indicates that past declines may be reversed by new factors which could lead to future population growth. The general demographic trend prior to 1970 was one of declining rural population, only partially balanced by increase in local town populations. Approximately 80% of the population was rural in 1910, declining to less than 30% in 1970 (U.S. Bureau of the Census, 1930 to 1970; Enviro Control, Inc., 1975). Rural population decrease has been caused largely by national decline in the labor intensiveness of farm production.

Township population data (1960-1970) show that growth is occurring along a corridor of townships which cross the county from Canton and Orion Townships on the east to Vermont Township on the west

Table IV-11. Historical Population Trends in Fulton County (U.S. Census of Population)

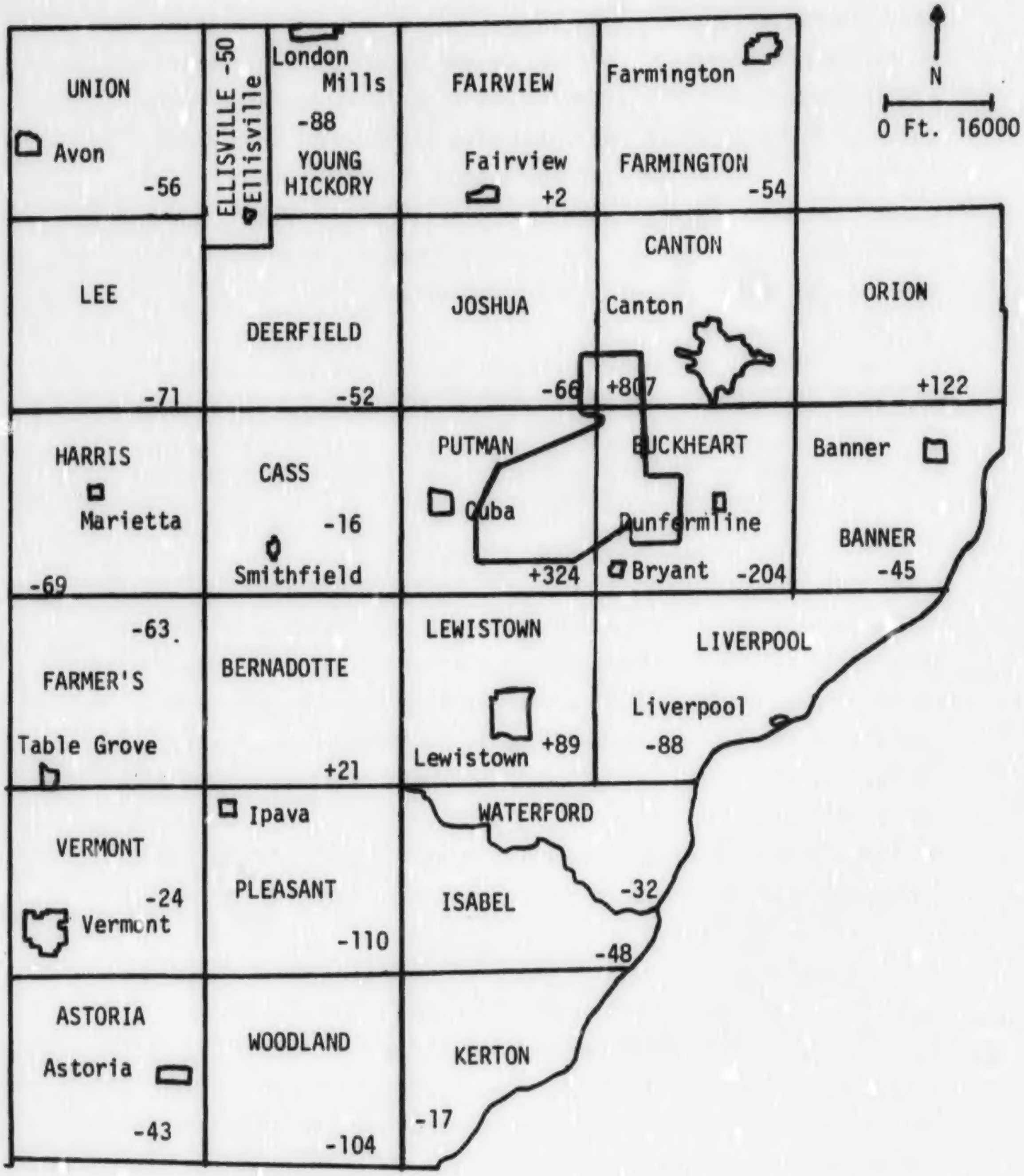
Township	Land Area	1970	1960	1950	1940	1930
Astoria	36.6	1,738	1,781	1,976	1,953	1,997
Banner	33.7	694	739	756	690	617
Bernadotte	37.7	383	362	369	671	643
Buckheart	35.1	1,770	1,974	2,257	2,320	2,589
Canton	35.7	15,887	15,080	15,056	14,162	13,937
Cass	38.7	819	835	948	1,018	987
Deerfield	34.8	424	476	528	560	630
Ellisville	13.8	230	280	319	423	331
Fairview	36.4	923	921	1,029	1,065	1,113
Farmers	35.7	498	561	617	967	976
Farmington	36.2	3,998	4,052	3,960	3,937	3,941
Harris	33.8	520	589	680	903	813
Isabel	29.5	300	348	387	507	460
Joshua	35.8	641	707	813	857	874
Kerton	27.3	178	195	283	370	338
Lee	37.2	404	475	496	594	627
Lewistown	35.7	3,252	3,163	3,237	2,943	2,884
Liverpool	42.2	844	932	1,057	1,071	955
Orion	36.5	898	776	789	900	781
Pleasant	37.9	1,018	1,128	1,199	1,299	1,333
Putman	34.8	2,115	1,791	2,025	2,169	2,123
Union	36.7	1,387	1,443	1,340	1,370	1,355
Vermont	36.7	1,399	1,423	1,490	1,590	1,602
Waterford	21.3	238	266	346	352	303
Woodland	38.7	596	700	843	976	976
Young Hickory	24.3	869	957	906	940	798
Community						
Astoria		1,281	1,206	1,308	1,292	1,189
Bryant		326	346	395	387	442
St. David		773	862	812	859	977
Canton		14,217	13,588	11,927	11,577	11,718
Norris		359	307	319	339	329
Smithfield		318	329	355	359	315
Ellisville		137	140	157	216	164
Fairview		601	544	568	528	522
Table Grove		469	400	481	480	463
Farmington		2,959	2,831	2,651	2,225	2,269
Marietta		169	201	178	193	202
Lewistown		2,706	2,603	2,630	2,335	2,249
Ipava		608	623	667	629	635
Cuba		1,581	1,380	1,482	1,620	1,479
Avon		1,013	996	870	803	799
Vermont		947	903	940	945	948
London Mills		612	-	-	-	432
Banner		235	247	215	172	-
Dunfermline		282	284	292	-	-
Liverpool		218	184	-	-	-

(see Figure IV-10). On both sides of this corridor, township population is declining. It is noteworthy that these declining areas are largely agricultural. The heavily strip-mined townships of Putman, Canton and Orion show significant population increase. Thus, in terms of population growth, economic development tends to coincide with mining activities. During this same period the communities of the county showed a pattern of population change consisting of three components:

- Major communities (Canton, Cuba, Lewistown, and Farmington) increased significantly
- Communities in the predominantly agricultural western part of the county (Ellisville, Ipava, Marietta, and Smithfield) declined
- Other communities grew slowly

The growth of major communities is presumably related to improved accessibility and a correspondingly increased radius of commercial center trade, combined with an increase in service activities. The decline of the western communities is presumably due to a decline in agricultural labor. Population decrease in small communities south of Canton is interpreted as representing a combination of decline in agricultural labor and bituminous coal mining, and increased attractiveness of growing urban centers nearby.

b. Population projections - Future population growth is predicted in the two most recent projections describing Fulton County and its surrounding water resources sub-region. The 1972-E OBERS Projections predict a 43% population increase between 1970 and 2020 for the 29-county water resources sub-area containing Fulton County. The basis given is the expected expansion of manufacturing. Increased opportunities in industry would facilitate the maintenance of the existing population, and would encourage population in-migration to the areas near new industrial plants. Consistent with the 1972-E OBERS Projections are population projections for Fulton County


UNION
Avon
-56
ELLISVILLE -50
Ellisville
London
Mills
-88
YOUNG
HICKORY
FAIRVIEW
Fairview
+2
Farmington
FARMINGTON
-54
N
0 Ft. 16000
LEE
-71
DEERFIELD
-52
JOSHUA
-66
CANTON
Canton
+807
ORION
+122
HARRIS
Marietta
-69
CASS
-16
Smithfield
PUTMAN
Cuba
+324
BUCKHEART
Dunfermline
Bryant
-204
Banner
BANNER
-45
-63
FARMER'S
Table Grove
BERNADOTTE
+21
LEWISTOWN
Lewistown
+89
LIVERPOOL
Liverpool
-88
VERMONT
-24
Vermont
Ipava
PLEASANT
-110
WATERFORD
-32
ISABEL
-48
ASTORIA
Astoria
-43
WOODLAND
-104
KERTON
-17

Township Population Change, Plus (+) or Minus (-)

ure IV-10. Fulton County Township Population Change, 1960-1970 (U.S. Census of Population) which have been released recently by the State of Illinois (see Table IV-12 below). These 1975 projections by the Bureau of the Budget, State of Illinois, predict a 29% increase in Fulton County's population between 1970 and 2020.

Table IV-12. Population Projections for Fulton County (Illinois Population Projections, 1975)

1970 Census	1975	1980	1985	1990	2000	2020
41,883	41,308	42,031	43,196	44,691	49,454	54,048

c. Family income - Median family income in Fulton County is relatively high when compared to other predominantly rural counties (Griffin and Chicoine, 1974). Principal causes for higher income are the availability of nearby manufacturing employment and historic labor-intensive modes of agricultural and strip-mine production. Much of the manufacturing employment pays high union wages. Many other, less well paid members of the work force are able to supplement their income by working shifts at the factories. Fewer people work on farms or at strip mines at present, but the skills required to operate increasingly sophisticated equipment enable them to command higher salaries.

Table IV-13 shows that the median family income has been increasing at approximately the same rate in Fulton County as in the entire country.

Table IV-13. Trends in Median Family Income (in 1967 dollars) (County and City Data Book, 1972, 1967, 1956; Statistical Abstract of the United States, 1974).

	1949	1959	1969
Fulton County	4235	5981	7852
United States	4603	6334	8486

2. Economic Characteristics

A number of local economic conditions will influence the overall impacts of the project. These conditions are described in the following section in terms of historic trends and current and probable future conditions. The analysis is divided into two major topics. The first consists of employment and governmental finances including land values in relation to tax base. These factors create a framework for an ensuing description of the agricultural, mining and manufacturing and the retail and wholesale trade sectors of the local economy which is the second topic.

a. Employment and fiscal trends - Table IV-14 summarizes a detailed history of employment trends in Fulton County. Several general trends are apparent in these data. Large declines in employment have occurred in the agricultural and mining sectors; little change has occurred in services and wholesale trade; manufacturing has fluctuated; and slight increases have occurred in retail trade.

Historical trends in revenues, expenditures, and public debts are shown for Fulton County in Table IV-15. These trends document a history of limited local financial resources.

Table IV-14. Employment Structure in Fulton County, Illinois (U.S. Census, County Business Patterns and Census of Government)

	1950	1959	1964	1969
Agriculture[1]	430[2]	384[2]	392[2]	123[1]

	1953	1959	1964	1967	1972
Manufacturing	2,601	919	2,683	3,605	2,551
Trade-Retail	1,726	612	1,715	1,898	2,004
Trade-Wholesale	276	185	180	227	221
Services	467	195	828	1,024	1,273
Mining	1,268	--	837	1,004	699
Contract Construction	133	265	134	127	192
Forestry & Other	7	20	10	--	--

	1957	1962	1967	1972
Government[3]	1,317	1,359	2,177	1,913
Education[3]				
Total	390	295	505	955
(Teachers)		(229)	(375)	(673)

[1] For Class 1-5 farms for worker by number of days worked -- 150 days or more.

[2] Workers by number of days worked -- 150 days or more.

[3] Local government employment and payroll in individual city areas.

Table IV-15. Trends in Governmental Finances in Fulton County, Illinois (U.S. Census of Governments)

Year	Total General Revenues (millions)	Total Expenditures (millions)	General Debt Outstanding (millions)
1972	$16.6	$16.4	$9.3
1967	$10.9	$10.8	$7.6
1962	$ 7.9	$ 7.6	$5.5

Because local public financial resources are heavily dependent on the property tax base, trends in land values are a useful indicator. The total value of real estate in Fulton County has declined significantly since 1971. As shown in Table IV-16, Banner Township is the only township in which there was a reversal of this erosion of tax base. This significant reversal was caused by the construction of a massive CILCO power plant in the mid-eastern portion of the county.

b. Agricultural activity - The agricultural sector of Fulton County's economy is in a state of rapid change. Data in Table IV-17 are descriptive of numerous agricultural trends which have developed since 1940. Discussion of these trends sets a framework for an analysis of future agricultural influences on the local economy.

Local agricultural trends appear to reflect a number of national patterns. Complicated, expensive farm machinery has made farming less labor intensive and has necessitated increases in the size of farms and the amount of skill required of the farmer. Increases in both farm size and required capital investment have tended

Table IV-16. Trends in the Total Value of Real Estate in Fulton County (Fulton County Assessor's Record, 1963, 1971, 1975)

Township	Total Value in 1967 Dollars		
	1963	1971	1975
Astoria	10,351,140	13,082,442	9,740,176
Banner	6,759,298	5,769,688	13,735,906
Bernadotte	4,322,675	5,098,330	4,049,181
Buckheart	11,656,337	11,758,275	9,851,977
Canton	69,792,894	66,997,284	55,167,531
Cass	6,394,912	5,948,055	4,737,494
Deerfield	5,222,632	5,359,248	4,277,267
Ellisville	2,321,338	2,033,798	1,673,854
Fairview	12,421,754	12,336,954	9,176,247
Farmers	6,593,026	6,410,532	5,026,814
Farmington	22,698,552	22,177,412	16,851,133
Harris	4,096,206	3,846,349	3,036,348
Isabel	4,481,162	5,083,303	3,990,668
Joshua	10,064,144	8,814,147	6,852,317
Kerton	3,467,412	3,784,055	2,983,249
Lee	6,855,263	7,165,266	5,817,557
Lewistown	16,809,122	16,767,504	14,974,874
Liverpool	7,656,009	8,375,394	7,262,166
Orion	5,873,750	6,657,339	5,743,451
Pleasant	8,948,596	8,173,083	6,378,639
Putman	12,016,250	16,230,825	14,997,607
Union	11,408,048	10,946,513	8,534,761
Vermont	10,187,653	9,380,073	7,214,698
Waterford	3,088,179	3,651,945	3,018,174
Woodland	5,479,451	6,266,587	4,959,408
Young Hickory	5,614,079	5,179,798	4,153,060
Total 100% Value	274,579,880	277,294,180	233,965,520

Note: Two sets of figures were used to calculate values. These are the percentage of assessed value and a deflator based on Illinois farmland values. Values for these are as follows:

	1963	1971	1975
Percent of value assessed	60%	50%	38%
Deflator used	.76	1.09	2.09

Table IV-17. Historical Agricultural Trends in Fulton County, Illinois (U.S. Census of Agriculture)

	1940	1945	1950	1959	1969
Farms	3,199	2,892	2,780	2,314	1,772
Land in Farms (acres)	501,867	489,318	489,919	496,427	464,314
Average Size of Farms (acres)	156.9	169.2	169.2	214.5	262.0
Land in Farms (%)	89.7	87.5	87.6	88.7	82.7
Farm Population	NA	10,614	NA	NA	5,890
Farm Operators on Farms	2,885	2,709	2,621	1,925	1,323
Hired Workers	739	376	842[1]	680[1]	NA
Absentee Farm Operators	165	173	131	176	311
Value of All Products Sold	$5,122,090	$13,093,966	$19,498,028	$25,140,633	$33,529,058
Total Cropland (acres)	251,635	269,964	261,894	293,928	302,083
Total Pastureland (acres)[2]		189,129	183,518	164,126	129,482
Corn (acres)	106,985	132,621	128,421	148,893	145,884
Sorghums (acres)	63	48	41	365	380
Oats (acres)	35,334	29,264	45,678	27,795	
Winter Wheat (acres)	33,832	13,348	13,348	19,071	12,578
Soybeans (acres)	24,916	46,783	31,037	39,451	56,302
Cattle and Calves	41,789	54,109	47,836	61,933	55,674
Cow Milked	12,395	11,762	9,953	4,002	-902
Hogs and Pigs	79,753	122,229-	161,982	204,669	120,332
Chickens	209,967	252,613	187,980	125,604	59,770
Value of All Products (1967)	$12,646,440	$23,988,145	$23,826,590	$26,523,367	$31,483,785

[1] Number of farms reporting the use of hired help.

[2] For class 1-5 farms (greater than $2,500 sales).

to increase corporate ownership of farms and the number of farm operators living in town. The consolidation of older, smaller farms has led to decline in farm population, and smaller farms which remain are not large enough to support the families living on them. Hence, an increasing number of these farmers have second jobs, which are generally shift work at factories in Peoria and Fulton Counties.

A number of trends are apparent concerning the type of farm goods being produced. Of great importance is the fact that the total value (in constant dollars) of all farm products has undergone substantial increase, despite a slight loss in the total acreage of farms. Decreases in the production of dairy products, poultry and wheat have been balanced by increases in the production of corn, soybeans and beef.

c. Mining and manufacturing - Strip mining of coal has been a major influence on the economy of Fulton County. Economic trends in mining are presented in Table IV-18 showing that the total number of employees has fluctuated, but has generally decreased since 1954. This decrease reflects technological improvement in the coal extraction process which make it a more capital intensive industry.

Table IV-18. Economic Trends in Mining in Fulton County, Illinois (U.S. Census of Mineral Industries)

	1954	1958	1963	1967	1972
Total Establishments	25	15	16	10	12
Types of Establishments					
Bituminous	24	12	14	8	6
Sand & Gravel	1	2	1	2	5
*Other	--	1	1	--	1
Total Employees	1,025	805	984	--	600
Value of Shipments	$23,937,000	$19,506,000	$28,229,000	--	$28,600,000
Value of Shipments (1967)	$27,336,054	$20,617,842	$29,866,282	--	$24,024,000

* Includes chemical and fertilizer minerals, coal mining services, and oil and gas extraction.

The countywide total number of strip mining companies has also decreased, resulting primarily from the economies of scale gained by merging the resources of two or more firms. Value of shipments, a measure of total productivity, has declined in total dollar value since 1963. This decline may reflect the influence of increasingly stringent national air pollution regulations on the value of high-sulfur coal, such as the coal extracted locally.

Manufacturing in and near Canton is dominated by the International Harvester plant. However, manufacturing plants west and south of Peoria exert considerable influence on employment in the Canton area. As shown in Table IV-19, there are no clearly discernable manufacturing trends. Importantly, though, the data show that there are few firms employing over 100 people. Other, smaller firms form a fairly diverse, although not strong, industrial base. According to the 1972-E OBERS Projections, the total value of manufacturing output in the sub-region containing Fulton County is expected to increase by 218% between 1980 and 2020. This projected increase could replace job losses resulting from expected decline in the employment on farms, in mines and in small town retail trade and services.

d. Retail and wholesale trade - Historically, most trade activities have been consolidated in a small number of central places. Canton is the major urban area in Fulton County, but trade activities have also been attracted to Lewistown and Farmington. Peoria and Pekin, however, are the dominant centers of trade in the entire Region.

Trends in retail activities are shown in Table IV-20. The most important trend is the high rate of increase in the total volume of retail sales. The current status of Canton as a central marketplace is demonstrated by a recent survey which shows that 84% of the inhabitants of Canton do more than half of their shopping in Canton (Canton Chamber of Commerce, 1975). There appears to be progressively

Table IV-19. Historical Manufacturing Trends in Fulton County, Illinois
(U.S. Census of Manufactures)

I. Selected Data

	1939	1947	1954	1963	1972
Number of Establishments	21	30	30	29	26
Total Employees	1,007	3,178	2,065	2,617	--

II. Number of Establishments by Type

SIC*	Category	1947	1954	1963	1972
20	Food and kindred products	8	7	5	3
23	Apparel and related products	2	2	1	1
24	Lumber and products except furniture				
25	Furniture and fixtures	2	1	--	1
27	Printing and publishing	8	8	10	7
28	Chemicals and allied products	1	1	--	--
31	Leather and leather products	3	--	--	--
32	Stone, clay and glass products	--	2	4	1
33	Primary metal industries	2	--	1	1
34	Fabricated metal products	1	2	1	1
35	Machinery (except electrical)	2	1	1	4
36	Electrical machinery	--	--	1	1
37	Transportation equipment	--	--	1	1
38	Instruments and related products	1	1	--	--
CAO	Central Administrative Offices	--	--	--	1

III. Industries (Establishments) Employing 100 or More

SIC*	Category	1947	1954	1963	1972
23	Apparel and related products	--	--	1	1
33	Primary metal industries	--	--	1	--
35	Machinery (except electrical)	1	1	1	1
37	Transportation equipment	--	--	--	1

*SIC: Standard Industrial Classification, a code of industrial classifications issued by the U.S. Office of Management and Budget

Table IV-20. Trends in Retail Trade in Fulton County, Illinois
(U.S. Census of Business; Census of Retail Trade)

I. Selected Data -- Number of Establishments

SIC*	Major Groups	1948	1954	1958	1963	1967	1972
52	Lumber, building materials, hardware	27	60	67	48	50	34
54	Food stores	54	87	89	81	55	47
55	Automotive dealers, except 554	42	47	40	42	42	38
554	Gasoline service stations	86	83	80	63	66	63
56	Apparel & accessories stores	25	29	24	31	28	28
57	Furniture, home furnishings, equipment	32	36	33	36	24	20
58	Eating & drinking places	121	105	113	97	92	97
591	Drug stores & proprietary stores	19	21	16	12	15	15

II. Retail Trade Volume in Thousands of 1967 Dollars

SIC*	Category	1948	1954	1958	1963	1967	1972
52	Lumber, building materials, hardware	7,217	7,061	6,484	5,609	9,212	4,046
54	Food stores	12,841	12,184	12,963	13,609	15,453	16,269
55	Automotive dealers, except 554	8,561	13,066	11,039	12,611	13,059	14,823
554	Gasoline service stations	3,744	4,501	5,305	4,516	5,551	5,472
56	Apparel & accessories stores		2,239	1,910	2,845	3,281	3,794
57	Furniture, home furnishings & equipment	2,467	2,829	2,220	1,613	1,977	2,783
58	Eating & drinking places	3,495	3,276	3,567	3,684	3,970	5,003
591	Drug stores & proprietary stores	1,318	1,391	1,388	1,574	1,758	2,075
	Total Retail Trade Volume	47,632	54,370	56,557	59,960	67,543	63,338
	Deflators (Consumer Price Index)	1.387	1.242	1.155	1.058	1.000	0.799

*SIC: Standard Industrial Classification, a code of industrial classifications issued by the U.S. Office of Management and Budget less retail orientation in Canton to the Peoria and Pekin markets. However, specialized goods such as bricks, sports car equipment, and furs are available only in Peoria or Pekin. Peoria is a locus for specialized commodities and services as well as for comparison shopping.

The number of wholesale establishments and the total volume of wholesale sales have each increased substantially since 1948 (Table IV-21). These trends further reflect less orientation toward the Peoria market. However, Peoria offers a great diversity of wholesale firms, most of which have larger inventories.

Table IV-21. Trends in Wholesale Trade in Fulton County, Illinois
(U.S. Census of Business; 1972 Census of Wholesale Trade)

	1948	1954	1958	1963	1967	1972
I. Selected Data						
Number of Establishments	47	55	51	51	52	77
Number of Employees	244	228	239	195	229	380
Sales in Thousands of 1967 Dollars	16,696	16,301	19,950	19,295	20,761	33,401
II. Types of Establishments						
Number of Merchant Wholesalers	14	13	19	15	14	59
Number of Other Operating Types*	33	42	32	36	38	18

Note: Data on employment differs from that listed in Table IV-15. The difference is that the above data are aggregated by place of residence; those in Table 1 are aggregated by place of employment.

F. LAND USE AND DEVELOPMENT

Land use is one physical manifestation of social and economic values. In the following section, data describing past and current land use, as well as projected social and economic trends, are used to project future land use.

1. Established Uses of Land

The following discussion of land use is weighted toward current information; a detailed historical record of land use in Fulton County is not available. The discussion is divided into two major categories:

- Land use patterns
- Use of strip-mined land.

a. Land use pattern - The only available county-wide inventory of land use was made in 1968 (Harland Bartholomew and Associates, 1969). Recent low rates of social and economic change in Fulton County indicate that 1968 data reliably approximate current conditions. According to these data, most of the land in Fulton County is devoted to unintensive use. Approximately 88% of the land is either covered by forest or water, used for agriculture, or is vacant. Fallow strip-mined land covers nearly 7% of the land. Public and semi-public areas, mostly unintensively used, cover over 3% of the county. Only the 2% of remaining land is used intensively. Intensive uses amount to a little over 1% residential, less than 0.5% commercial, and about 0.7% industrial.

While quantitative estimates of past land use are generally unavailable, some estimates of agricultural and strip-mining acreage were obtained. Data from the Census of Agriculture (see Table IV-17, page IV-42) show that the percent of land in the county devoted to agriculture decreased from 87.5% in 1945 to 82.7% in 1969. This change was accompanied, from 1945 to 1969, by a decrease of 60,000 acres of pasture and an increase of 32,000 acres of cropland. By 1974 approximately 5,000 acres of strip-mined land had been added to the 1969 county-wide total of 40,000 acres (Sandberg, 1973). Due to recently increased requirements for land reclamation, this added acreage has been reclaimed to a degree much closer to its original state than were most of the 40,000 acres.

A representation of land use near the project area is provided in Figure IV-11. This map shows the strong orientation of intensive uses to Canton and, to a lesser extent, Lewistown. Wee-Ma-Tuk Hills and Spoon River College are the major intensively developed sites near the project area; both exhibit potential for future growth.

The predominant urban land use is residential, accounting for almost 38% of the total urban area (Harland Bartholomew and Associates, 1969). Most industrial activities are located in or adjacent to urban areas; remaining rural industrial operations are mostly agriculturally oriented. Strip-mining activities are located in the central, northeastern, and southwestern sections of the county. Agricultural activities are located throughout the county.

Substantial, widely scattered forests are located along streams and in areas where steep slopes have limited the use of the land. Major conservation districts are located along the Illinois River. Parks and private recreation clubs occupy many other scattered areas. Hunting, fishing, and camping are the primary recreational activities. Most recreation is seasonal and requires an extensive amount of land per user. Most regional recreation is concentrated at Dickson Mounds State Park and throughout the Spoon River Valley. Parks are planned for several sites near the Spoon River (Bordner, 1975).

The major land holders in Fulton County are the mining companies, incorporated firms and owners of a number of large farms, as well as MSDGC. Land holdings as of 1973 are detailed in Table IV-22 on the following page, indicating that large portions of the county are owned by relatively few individuals and corporations. The existence of large tracts of land makes it relatively easy to buy land for recreation, conservation, industrial development, or strip mining.

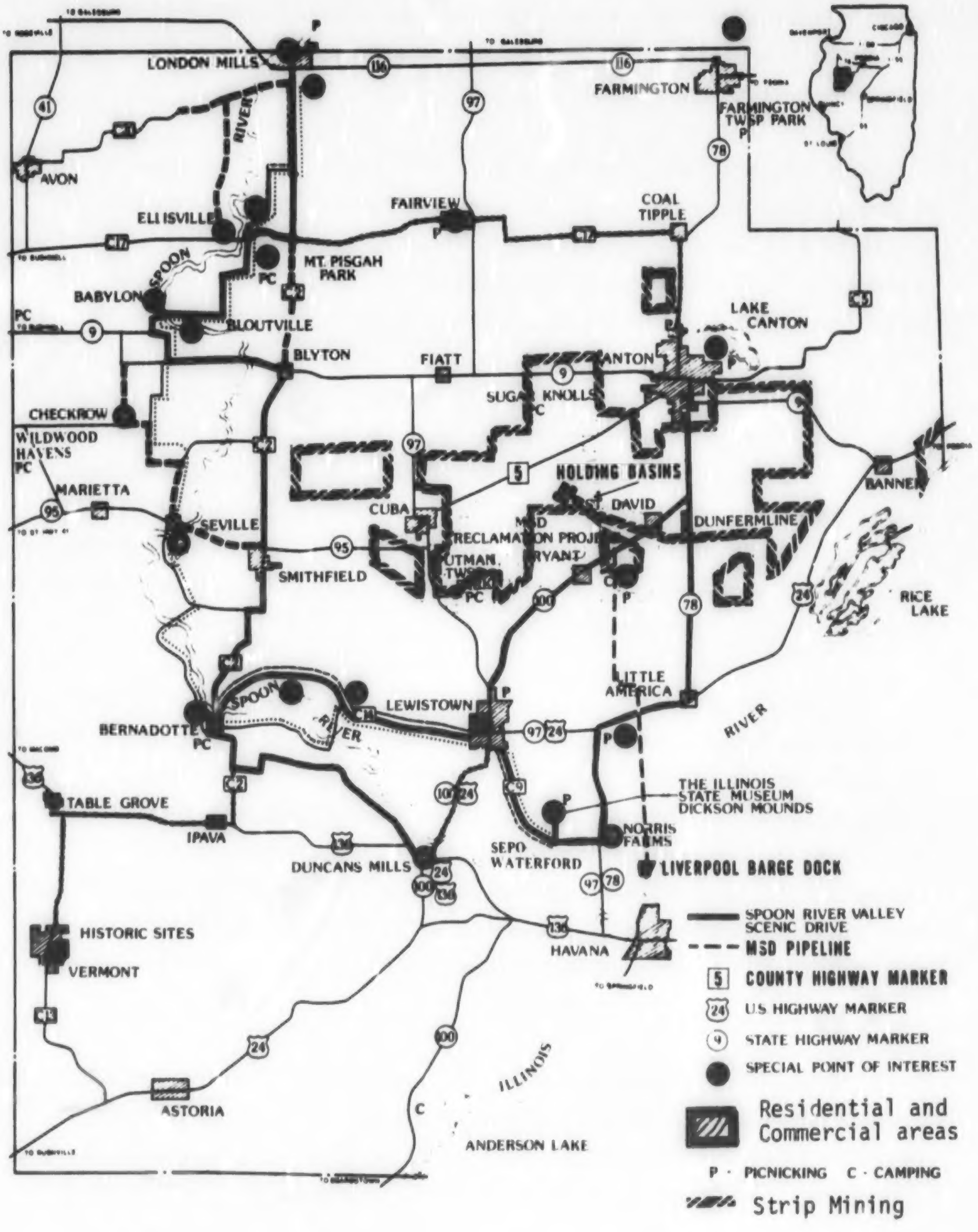

LONDON MILLS
AVON
ELLISVILLE
FAIRVIEW
FARMINGTON
FARMINGTON TWSP PARK
COAL TIPPLE
MT. PISGAH PARK
SPOON
RIVER
BABYLON
BLOUTVILLE
BLYTON
FIATT
LAKE CANTON
CANTON
SUGAR KNOLLS
CHECKROW
WILDWOOD HAVENS
MARIETTA
HOLDING BASINS
ST. DAVID
DUNFERMLINE
BANNER
CUBA
MSD RECLAMATION PROJECT
PUTMAN TWSP
BRYANT
SEVILLE
SMITHFIELD
RICE LAKE
LITTLE AMERICA
LEWISTOWN
BERNADOTTE
RIVER
TABLE GROVE
IPAVA
DUNCANS MILLS
SEPO
WATERFORD
THE ILLINOIS STATE MUSEUM DICKSON MOUNDS
NORRIS FARMS
LIVERPOOL BARGE DOCK
HISTORIC SITES
VERMONT
HAVANA
ILLINOIS
ASTORIA
ANDERSON LAKE
TO GALESBURG
TO PEORIA
TO SPRINGFIELD
SPOON RIVER VALLEY SCENIC DRIVE
MSD PIPELINE
5 COUNTY HIGHWAY MARKER
24 US HIGHWAY MARKER
9 STATE HIGHWAY MARKER
SPECIAL POINT OF INTEREST
Residential and Commercial areas
P · PICNICKING C · CAMPING
Strip Mining

Figure IV-11. Fulton County Land Use, 1968
(Harland Bartholomew and Associates, 1969)

Table IV-22. Major Land Holders in Fulton County, 1973
(Fulton County Plat Book, 1973)

Land Holders	Acres	Percent
Total County Land	561,152.00	100.00
Mining Companies	41,716.58	7.43
Incorporated Farms (9 companies)	25,382.90	4.52
Other Major Farms (18 owners)	12,576.05	2.24
MSDGC	9,711.31*	1.73
State of Illinois	4,266.33	0.76
Private Recreation	2,912.28	0.51
Banks	1,998.90	0.35
Major Developers	1,676.44	0.29
Industrial Firms	832.40	0.14
Total	101,073.19	18.01

*Acreage is 15,528 as of August 1975

b. Use of strip-mined land - A 1973 survey identified land use in currently and formerly strip-mined areas (Sandberg, 1973). Table IV-23 summarizes the existing use of reclaimed and unreclaimed strip-mined lands. Unreclaimed lands were defined as "areas where no attempt has been made to reclaim stripped land to a productive use". Reclaimed lands were defined as "areas where the land has been leveled to reasonable slopes and surface drainage has been restored". Fulton County contains about 21,600 acres of unreclaimed and 15,500 acres of reclaimed strip-mined lands. Most unreclaimed areas are in woodlands, light cover, or no cover; most reclaimed areas are in light cover, light pasture, or heavy pasture. In 1973, none of the unreclaimed mining sites and less than 3% of the reclaimed sites were used as cropland.

2. Projected Uses of Land

The 1990 land use plan for Fulton County designates future land use on the basis of 1968 estimates of future demographic and economic

Table IV-23. 1973 Land Use Survey of Strip-Mine Lands in Fulton County, Illinois (Sandberg, 1973)

Type of Land	Total Unreclaimed Lands			Reclaimed Lands
Use	Unreclaimed Lands	Mine Wastes	Water Areas	
A. Woodlands	8518	-	-	392
B. Light Cover	6547	-	-	4064
C. Light Pasture	1011	247	-	5992
D. Heavy Pasture	-	-	-	3123
E. Cropland	-	-	-	405
F. Residence	-	-	-	251
G. Commerce	-	-	-	-
H. Industry	222	316	-	-
I. Landfill	15	-	-	-
J. Public Recreation	-	-	-	-
K. Private Recreation	190	-	374	241
L. Public & Semipublic	-	-	9	-
M. Conservation-Wildlife	-	-	3888	-
N. Unused-No Cover	5068	1978	-	988
TOTAL ACRES	21,571	2,541	4,271	15,456
VALUE PER ACRE*		$259	**	$323

* Value Per Acre = 100% value in 1967 dollars

** Does not include the value of mining equipment and structures.

Notes:

A. Woodlands included dense, forested lands where the ground surface was not visible or rarely seen in the aerial photographic interpretation.

B. Light Cover describes areas with surface cover of some form or other, usually grasses, low shrubs and scattered trees.

C. Light Pasture often included newly reclaimed areas where surface foliage was provided for grazing. In other natural areas, the distinction between light cover and light pasture was made on the basis of visible animal paths from fields to barns or sheds.

D. Heavy Pasture included areas where large-scale grazing operations were found. Stock trails, animal pens, feeding stations and the like were often used to determine the scale of operation.

E. Cropland is determined by the visible pattern of planted or harvested crops.

F. Residence Areas are determined by the outline of buildings, driveways, and arrangement of lots.

G. Commerce includes small commercial facilities usually associated with highways in the smaller communities.

H. Industry includes active mining areas, railroads, coal tipples and similar intensive operations.

I. Landfill is an area where solid waste materials are buried in a deep trench and covered with dirt.

J. Public Recreation Areas are owned by a public agency or unit of local government and are made available for use by the general public.

K. Private Recreation Areas include golf clubs, private reserves, camps and the like and are available to members or owners, not the general public.

L. Public and Semipublic Lands include schools, churches, cemeteries, public sewage plants and similar uses.

M. Conservation-Wildlife Areas include water areas and surrounding lands which, by virtue of proximity, create a habitat for wildlife.

N. Unused-No Cover Lands are areas where soil conditions are not conducive to growth of natural vegetation. These lands are often associated with mine waste areas.

change. Since the anticipated changes were minor, these future designations are closely related to the existing land use pattern (Figure IV-11, page IV-50).

Residential uses are expected to increasingly concentrate in and near the established urbanized areas. Major residential growth is expected to the east and northwest of Canton; to the north, east, and west of Lewistown; to the west and northeast of Farmington; and around Avon, Cuba, and Vermont. Increases are anticipated in the number of single-family, multi-family and mobile home dwellings in tract subdivisions, and decreases are expected in the number of farm residences.

Commercial uses are predicted to concentrate in the central business districts of Canton, Lewistown and Farmington. The plan anticipates major industrial areas near Liverpool and in and near Canton, Lewistown, and Farmington. The anticipated major new public lands are six reservoirs with adjacent forest preserves (see Figure IV-13, page IV-59). Conservation and recreation expansion would concentrate in the surroundings of the Spoon River Scenic Drive along the river from Dickson Mounds to London Mills.

Most future strip mining is expected to occur north of Canton. A major emphasis in the county's land use policy is the reclamation of strip-mined lands. Stringent conditional use permits regulate the nuisance aspects of strip mining and require substantial reclamation of the land. Land use is also regulated on a county-wide basis by a zoning ordinance, and Canton, Cuba and Farmington have separate ordinances.

3. Land Development Potential

The potential for actual land development depends upon the interaction among land suitability, accessibility and attractiveness, with the social and economic factors of land use demand discussed earlier. The suitability, accessibility and attractiveness of land are the physical components of development potential; they deal with the conditions of the site, its location and aesthetics. These factors are discussed separately in this section.

a. Land suitability - Suitability of the project site for various land uses is affected by topography, soils and drainage. The application fields, once leveled and graded, have a gently sloping surface which would easily accommodate a variety of land uses, including roads, housing, industry, row-crop farming and livestock feedlots. Slightly steeper surrounding slopes are better suited for pasture and tree farming. Erosion and construction problems on the steepest slopes make them best suited for unintensive recreation and conservation.

Problems of settlement with unconsolidated soils in the strip-mined sections of the project area would most likely make it prohibitively expensive to accommodate hard surface roads, underground utilities, and residential or industrial structures. Current levels of available plant nutrients and organic matter make these soils unsuitable for intensive agriculture. Soils of the undisturbed place lands do not present these limitations.

Drainage control systems developed with the application fields increase their suitability for potentially polluting land uses, including industries with hazardous spill potential, livestock feedlots and intensive crop production involving high application rates of fertilizers and pesticides. Polluted runoff and erosion are much more difficult to contain outside the application fields.

b. Land accessibility - Of course, transportation has a marked influence upon the potential for land development. Access to major population centers significantly affects the number of potential visitors to regional recreation and conservation sites. Access to Peoria and surrounding manufacturing zones strongly influences the extent of large-scale residential development.

The project area is not easily accessible from Peoria and and other population centers because the roads in Fulton County are generally two-lane pavements of poor quality. Until high-speed roads are built, it is expected that most traffic will be oriented locally. Figure IV-12 is a graphic representation of traffic volumes in 1965. If a proposed limited-access highway were built between Canton and Peoria, significant increases in the inter-city traffic volume could result. However, construction of this road has not been authorized, and once authorized will take many years to complete. Freight service is available on three railroads in Fulton County. The Rock Island Railroad provides passenger service in Peoria. An airport in Canton can handle light planes (3,900 ft. runway), and the Greater Peoria Airport has regularly scheduled jet service. Docking facilities at Liverpool and Havana provide water transportation to the Chicago region and Lake Michigan and to points south along the Illinois and Mississippi Rivers.

The quality and availability of utilities also heavily influences land development. At the project site, electricity is readily available, and bottled gas is used extensively for local farms and mobile homes. Natural gas pipelines are not expected in the project area because of the expense involved in building through disturbed soils and the risk involved in predicting gas prices and availability. The only large supply of water in the project area is from wells; this source is too high in dissolved minerals to be used conveniently or in quantity for residential or industrial purposes. Surface reservoirs are being planned at sites near Canton and along the Spoon River for future supplies of high quality water.

c. Land attractiveness - Factors which affect the attractiveness of land are landscape quality, historic resources, and nuisance factors. Landscape quality varies according to subjective interpretations of the viewer. Hunters and fishermen are attracted to the abundant prairie wildlife habitats and the crystal blue

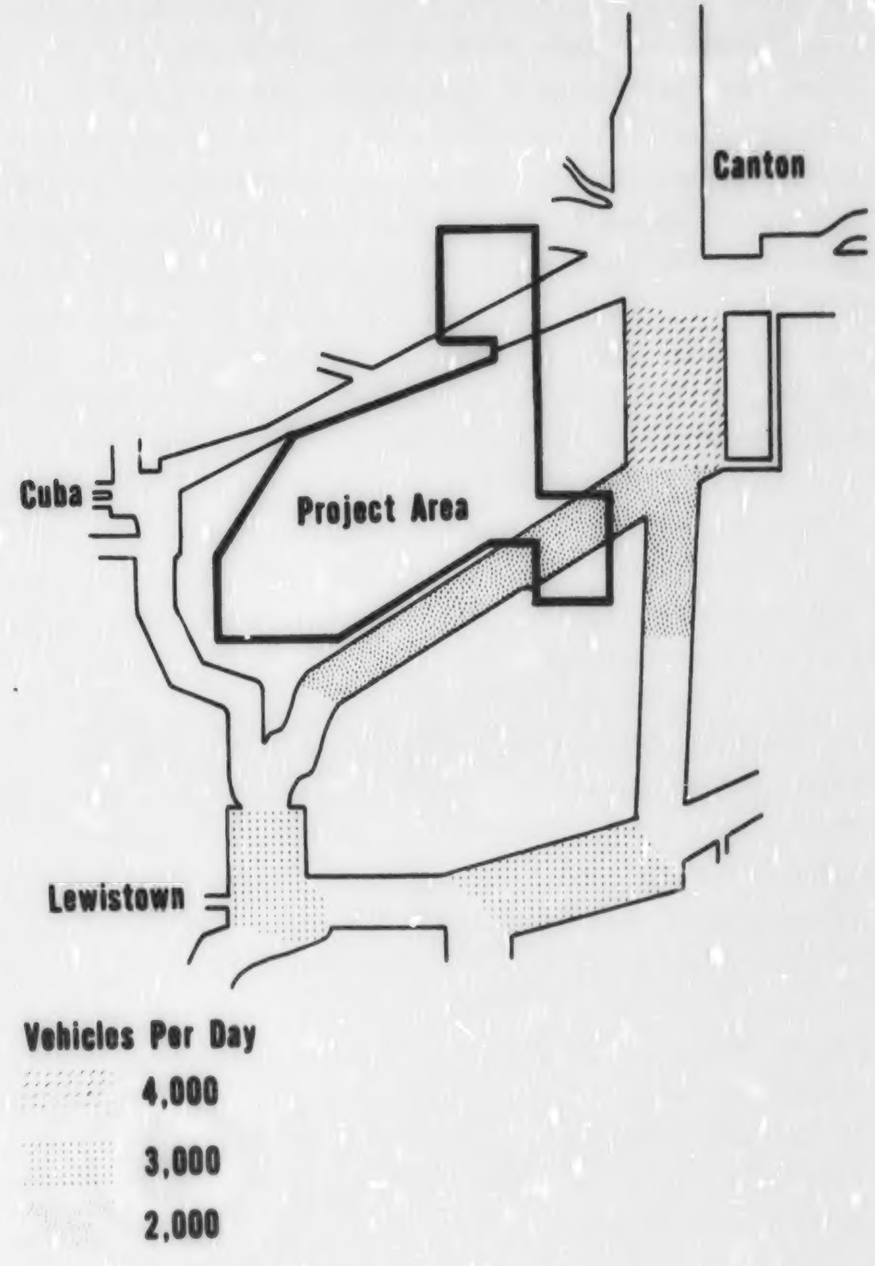

Canton
Cuba
Project Area
Lewistown
Vehicles Per Day
4,000
3,000
2,000

Figure IV-12. Average Traffic Volumes Near the Project Area
(1965 data. Harland Bartholomew and Associates, 1969)

lakes of the project area. Farmers may dislike the visible loss of farmland to the strip mine shovel. Prospective rural homeowners may shun the barren waste of unreclaimed mine spoils. One method of evaluating landscape quality is to assess the diversity of landscape elements. The project area contains streams and clear blue lakes, contrasting with the greens and browns of the landscape; steep slopes and level fields; dense, cultivated vegetation on the application fields and sparse vegetation elsewhere.

The influence of historical factors on development of the project site is probably nil. Farming became an early major influence when the land that was to become Fulton County was made part of a larger area known as the "Military Tract," designated for use in paying soldiers for service in the War of 1812. The second historical influence is that of coal mining. The first mining of shallow coal deposits pre-dated the Civil War. Since World War I, highly mechanized strip mines have extensively altered the landscape in Fulton County. Neither of these influences, however, have produced tangible historic resources at the project site.

Dominant nuisance factors influencing the attractiveness of the project site are the odors emanating from sludge holding basins and dispersing from sludge spray during spraying operations, and the visual blight of sludge spraying. Neither source of nuisance is a permanent deterrent to human settlement since each would be abandoned in the event of an alternative use for the project site. However, in the interim these nuisances may be decisive in their affect on nearby residential expansion (e.g., Wee-Ma-Tuk Hills).

G. ENVIRONMENTALLY SENSITIVE AREAS

Fulton County has a number of environmentally sensitive land areas and resources. These are depicted in Figure IV-13 and identified in the ensuing discussion of water, land, and cultural resources.

1. Water Resources

Surface water is particularly important in Fulton County because most of the groundwater contains over 1,500 ppm of dissolved minerals and is unsuitable for public water supply without expensive treatment. Surface water, having a considerably lower concentration of dissolved minerals, is therefore a valuable source for public and industrial water supplies.

Six multi-use reservoirs (forest, conservation, recreation, and water supply) are planned to maximize future use of surface water supplies. Pollution in the Spoon River or Copperas Creek watersheds would severely degrade the value of these resources. The entire length of the Spoon River is especially valuable because it is one of the last remaining natural streams in the State of Illinois.

Wetland areas comprise another environmentally sensitive local resource; they are located primarily in the flood plain of the Illinois River and are not directly affected by the project. Major wetland conservation areas include Rice and Anderson Lakes, which serve as habitats for large populations of game and migratory birds. Lakes and ponds created by strip mining in the project area are currently important to a flock of Canada geese.

2. Land Resources

Besides the flood plain wetlands, there are four upland types of environmentally sensitive land in Fulton County. The first of these, strip-mined land, is particularly susceptible to damage by erosion. Sparse vegetative cover, steep slopes, and poor soil permeability are three factors contributing to the erosion of unreclaimed or incompletely reclaimed strip-mined areas. Erosion diminishes downstream water quality and accelerates sedimentation in downstream reservoirs.

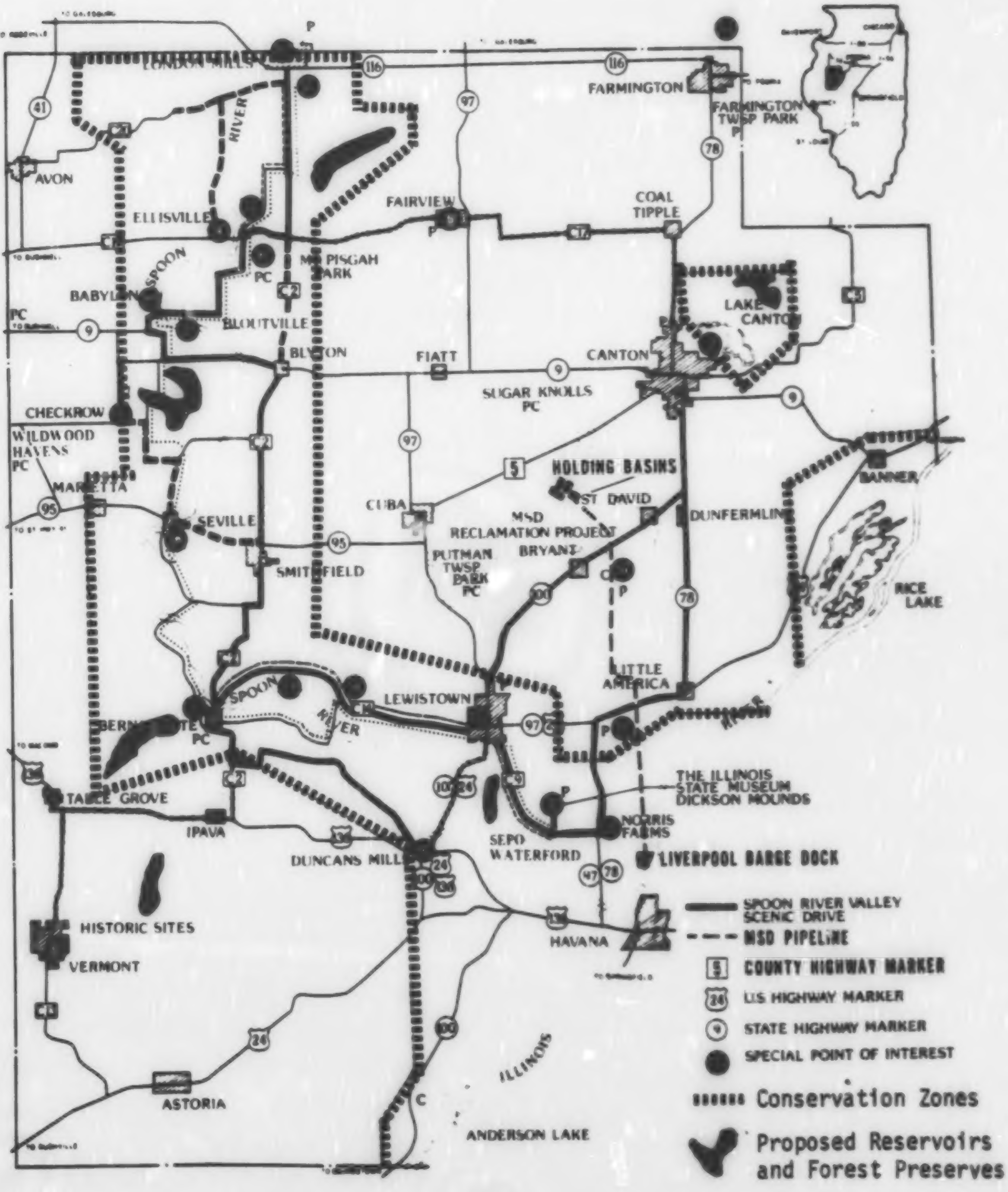

LONDON MILLS
FARMINGTON
FARMINGTON TWSP PARK
AVON
ELLISVILLE
RIVER
SPOON
FAIRVIEW
COAL TIPPLE
MT PISGAH PARK
PC
BABYLON
BLOUTVILLE
BRYTON
FIATT
CANTON
LAKE CANTON
SUGAR KNOLLS PC
CHECKROW
WILDWOOD HAVENS PC
MARIETTA
HOLDING BASINS
ST DAVID
CUBA
MSD RECLAMATION PROJECT
BRYANT
DUNFERMLINE
BANNER
SEVILLE
SMITHFIELD
PUTMAN TWSP PARK PC
RICE LAKE
LITTLE AMERICA
LEWISTOWN
BERNADOTTE PC
TABLE GROVE
IPAVA
DUNCANS MILLS
SEPO
WATERFORD
THE ILLINOIS STATE MUSEUM DICKSON MOUNDS
NORRIS FARMS
LIVERPOOL BARGE DOCK
HISTORIC SITES
VERMONT
HAVANA
ILLINOIS
ASTORIA
ANDERSON LAKE
SPOON RIVER VALLEY SCENIC DRIVE
MSD PIPELINE
COUNTY HIGHWAY MARKER
U.S HIGHWAY MARKER
STATE HIGHWAY MARKER
SPECIAL POINT OF INTEREST
Conservation Zones
Proposed Reservoirs and Forest Preserves

Figure IV-10. Major Environmentally Sensitive Areas in Fulton County (Harland Bartholomew Associates, 1969)

Prime agricultural land, watershed woodland, and tallgrass prairie are valuable natural resources. The prime agricultural lands in Fulton County are characterized by thick, deeply weathered loess soils, small topographic relief, and few stones in the upper soil layers. Large fields of these prime soils are well suited for highly mechanized methods of agricultural production.

The main values of local woodland are its recreation potential and ability to protect the quality of surface water by stabilizing soils and reducing runoff volume and velocity, which are key factors in erosion. The local importance of surface water in Fulton County intensifies the value of these woodlands. The most valuable woodlands are found in the watershed of the Spoon River valley and in watersheds upstream from each of the planned reservoirs.

Prairie, particularly tallgrass prairie, such as that being planted as a part of the Big Bluestem Management Plan, is environmentally valuable for a number of reasons. First, it would preserve a rare portion of Illinois natural history. In addition, such prairie can serve as a conservation area for wildlife, including such locally rare species as the greater prairie chicken, sharp-tailed grouse, trumpeter swan, and the sandhill crane. Finally, prairie grasses, with their deep abundant roots, provide excellent soil-building and erosion control characteristics.

3. Cultural Resources

Fulton County has numerous areas devoted primarily to outdoor recreation. Local recreation needs of many residents are met by public park districts in Canton, Lewistown, and Farmington. Public recreation needs of a more regional scope are served by a 400-acre tract of land which has been made available to the county by the MSDGC. Private recreation includes an area at Lake Wee-Ma-Tuk, several private hunting and fishing areas on strip-mined lands, and campsites with trails for use of off-the-road vehicles on private lands. The most environmentally sensitive recreation resources are those located adjacent to streams and lakes.

Fulton County has a number of historic and archeological sites. Old mansions, "underground railway" stations, and early shaft coal mines are located throughout the county. An extensive prehistoric mound-building culture left over 800 mounds in the area that is now Fulton County. The most important of these, the Dickson Mounds, are preserved as a state museum.

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V. COST-EFFECTIVENESS OF ALTERNATIVE METHODS OF SLUDGE PROCESSING AND DISPOSAL

The cost-effectiveness of alternative methods of sludge processing and disposal must be evaluated in terms of system costs, reliability, and environmental effects. For example, the least-cost alternative may be unacceptable if it would incur severe environmental impacts that cannot be mitigated at reasonable cost. An alternative having the least potential for environmental harm may be infeasible if its required resource commitment is not economically justified. Substantial uncertainty in the state-of-the-art of an alternative method still in an experimental phase may cancel its potential cost savings or environmental advantages. Trade-offs among these three factors can lead to the identification of the most cost-effective alternative.

The optimization of these factors requires the separate evaluation of subsystem options for sludge processing and disposal, which can be classified as:

- Sludge dewatering subsystems
- Sludge stabilization subsystems
- Sludge disposal subsystems
- Sludge utilization subsystems
- Sludge transportation subsystems

Three to five options for each subsystem category are found in this chapter. Linkages between subsystems are also discussed. Candidate subsystems are assessed and inferior options are rejected on the basis of process reliability, unit costs, and environmental implications. Subsequently, system alternatives are assembled using compatible combinations of available and feasible subsystems. A matrix summarizing and comparing the system alternatives is presented at the conclusion of this chapter.

A. SLUDGE DEWATERING SUBSYSTEMS

Sludge dewatering is an important process in sludge volume reduction which renders sludge handling more manageable. Available dewatering processes include:

- Air drying on sand beds
- Thickening by gravity sedimentation or flotation
- Dewatering by centrifugation and vacuum filtration
- Dual cell gravity dewatering and freezing-thawing techniques
- Use of moving filter screens or a belt-filter press or vertical screw press.

Among these processes, concentration of raw sludge by air drying on sand beds and gravity sedimentation or flotation, followed by vacuum filtration or centrifugation, are the most frequently encountered processes and have received a great amount of study, research and testing. Four processes are described separately in this section.

1. Air Drying

Air drying of sewage sludge on sand beds has been the most common method of dewatering. The process is accomplished by drainage, which predominates during the early stages, and evaporation. Approximately 60 to 85% of the water is removed by drainage (Swanwick, 1962). The rate of drainage depends on sludge characteristics and initial solids concentration.

Evaporation rates, and the ultimate moisture content of air dried sludge, depend upon air temperature, wind speed, amount and rate of precipitation, sunshine, and relative humidity. Drying of sludge takes approximately 6 weeks during the summer (Fleming, 1959), and about two times longer in the winter. The drying process can be hastened by covering the beds and providing an artificial heat source.

Sludge characteristics have a marked influence upon drying rates. In general, sludges containing grit dry more quickly than those containing grease. New sludge dries faster than aged sludge, and primary sludge dries faster than secondary sludge. Digested sludge cracks earlier and dries faster than raw sludge. It is important that sludge be well digested for optimum drying (Burd, 1968). After the sludge has been drained and dried sufficiently to be classified as spadeable (moisture content 60 to 70%), it is removed from the drying beds. The dried sludge is either landfilled or given away as soil fertilizer.

MacLaren has reported the annual capital costs of drying beds in Canada, for the year 1961 and a population equivalent of 10,000, to be $2.65 per dry ton. Annual operating costs, including hauling, ranged between $1 and $10 per dry ton, depending upon hauling distance. In general, the combined annual capital and operating costs for sand bed drying range between $3 and $20 per dry ton (Burd, 1968).

Based on the 1972 dollar and excluding hauling costs, operating and maintenance costs for sand beds with a capacity greater than 100 dry tons per day are less than $2 per dry ton per year (Stanley Consultants, 1972). Operating costs can be offset by selling dried sludge as a soil conditioner. Shredded sludge has been sold for as much as $6 to $10 per cubic yard (Burd, 1968), which is equivalent to $4.50 to $7.50 per dry ton. Air drying can be an economical method for sludge dewatering when low value land is available.

Environmental effects associated with sand beds include unpleasant odors and attraction of flies. In addition, to prevent contamination of groundwater, the drainage must be returned to the head of the treatment plant. When the sludge supernatant or drainage effluent is returned to the plant, fine solids and soluble solids are undifferentially recycled. This causes accumulation of nitrogen in the plant, reducing plant performance and increasing nitrogen levels in the plant effluent. This could lead to adverse impact on water quality of receiving streams and lakes.

2. Sedimentation-Flotation

Thickening of sludge may be accomplished by gravity settling or dissolved air flotation. Primary sludge and sludge from modified aeration systems are effectively thickened by gravity settling; sludge from activated processes such as contact stabilization and conventional activated sludge are more effectively thickened by air flotation.

Gravity thickening operates on the principle that the force of gravity will cause solids to be separated from the liquid phase in a settling tank. The weight of overlying solids compacts the sludge that is gathered at the bottom of the tank. This compacted sludge is withdrawn, and the supernatant is returned to the head of the plant. Sludge volume reduction can be as high as 50% by gravity settling. The solids content of the thickened sludge ranges from 3% or more for conventional activated sludge to as high as 15% for raw primary sludge. The degree of volume reduction or thickening depends primarily on the type of sludge and its volatile solids concentration.

In the flotation thickening process, solids are induced to float and thereby separate from the liquid phase. Before it is introduced to the bottom of the flotation unit, the sludge is finely mixed with air. When the sludge-air mixture enters the unit, minute air bubbles are formed which adhere to the sludge particles and render the solids buoyant. The sludge floats to the top and is skimmed off; the underflow is returned to the head of the plant. Flotation thickening generally produces sludge containing a higher level of solids than does gravity thickening. An achievement of 4% solids is considered normal for a flotation thickener, and 5 to 6% is not unusual. Chemicals are used on occasion to facilitate the thickening process. Primary variables in this process are pressure, recycle ratio, feed solids content, detention period, air-to-solids ratio, type and quality of sludge, solids and hydraulic loading rates, and the use of chemical acids.

Capital and operating costs of thickening equipment vary widely and are location dependent. Gravity thickening, in general, has higher initial costs and lower operating costs than pressurized flotation thickening. Maintenance and operating costs for gravity thickening amount to approximately $2 per dry ton of sludge per year (Burd, 1968). Annual capital and operating costs generally range from $1.50 to $5 per dry ton (Burd, 1968). Annual operating costs for flotation thickening range between $4 and $5 per dry ton, or $9 to $11 per dry ton with the use of chemical acids (Burd, 1968).

Combined annual capital, maintenance and operating costs for gravity thickening decrease with increasing plant capacity, ranging downward from $2 per dry ton for a plant size of 100 dry tons per day to $1.5 per dry ton for a plant size of 1,000 dry tons per day, based on the 1972 dollar (Stanley Consultants, 1972). The total annual costs for flotation thickening, without the use of chemical acids, are the same as for gravity thickening for this range of plant sizes.

The main environmental problems encountered with these processes are associated with energy consumption, odor, and noise. Flotation thickening requires more energy than gravity thickening. Because of unavoidable agitation from uprising bubbles in the flotation units, open flotation systems generally have more odor potential than gravity sedimentation units. In addition, flotation requires either air compressors or vacuum pumps, which are sources of noise. Flotation-concentration also requires the recycling of underflow and drain water back to the head of the treatment plant, leading to the same effects as described under air drying.

3. Centrifugation

This process occurs in a centrifuge, where centrifugal force applied to the solids separates them from the liquid phase. Three types of centrifuges are available for sludge dewatering; basket, disc, and solid bowl centrifuges. A number of factors must be considered in the selection of a centrifuge, the most important o which are detention time, hydraulic and solids loading, centrifugal force, permissible amount of solids slippage, desired concentration, and polyelectric dosage (Barnhill, Dresser and McKee, 1974).

The disc type centrifuge can concentrate activated sludge up to 7% solid at 6,000 rpm, but clogging of the sludge discharge nozzles necessitates frequent maintenance. Solid-bowl centrifuges thicken sludge to approximately 7 or 7.5% solids. In this type of centrifuge, a one-to-one mixture of primary and activated sludges can be thickened up to 9.8%, and solids recovery is better than 95%. A high concentration of solids is attainable with some sacrifice in solids recovery. In general, highly volatile sludge does not thicken as well as sludge low in volatiles. Centrifuge performance can be improved significantly with the aid of cationic polyelectrolytes.

Annual operating costs range between \$3 and \$8 per dry ton, and will run \$3 to \$10 more per dry ton when chemicals are used (Burd, 1968). The Scottish Development Department (1974), reporting on a study of centrifugation at a regional sludge-processing facility, stated that solid-bowl, Scroll-type centrifugation of raw sludge produced a cake with 23% solids at a total cost of \$29 per dry ton per year. According to Stanley Consultants, the total annual capital, operating and maintenance costs of centrifugation for a plant holding more than 500 dry tons of sludge per day are less than \$15 per dry ton, based on the 1972 dollar.

Adverse environmental effects resulting from centrifugation are slight. Because centrifuges consist of rapidly moving parts and motors, noise generation is a possible problem. Odor problems are minimal because the process is generally closed. Centrifugation also produces the accumulation of nitrogen in the plant as was noted for sand beds and sedimentation-flotation units; this reduces plant efficiency.

4. Vacuum Filtration

In the vacuum filtration process, sludge particles are separated from water by applying a vacuuming force to sludge on a filter medium. A vacuum filter consists of a compartmented drum rotating on a horizontal axis. About one third of the drum is submerged in a shallow tank containing the sludge slurry to be dewatered. The drum is covered with a filter medium which consists of either a cloth, screen or stainless steel coils. A vacuum is applied to the underside of the filter medium. Sludge cake is formed on the drum and eventually is scraped off and discharged to a conveyer belt or chute (Barnhill, Dresser and McKee, 1974).

Important sludge variables affecting filtration performance include volatile and solids content and sludge age and viscosity. Operating variables include the degree of vacuum, drum speed, degree of sludge agitation, filter medium, and conditioning of the sludge prior to filtration. Moisture content of the sludge cake produced varies between 80 and 85% for activated sludge, and between 70 and 75% for raw primary sludge, depending upon the nature of the sludge and the amount of conditioning chemicals used. Among many conditioning agents, ferric chloride and lime are the most frequently utilized.

Simpson and Sutton (1964) surveyed vacuum filtration costs at various sewage treatment plants and found total annual costs, including labor and supervision, chemicals and supplies, electric power, maintenance, and indirect costs,to vary between $5.34 and $30.17 per dry ton. Small plants usually had higher chemical costs. For large plants, vacuum filtration of composite digested primary sludge and activated sludge incurred operating costs close to $30 per dry ton per year. Stanley Consultants report that annual operating and maintenance costs range downward from $15 to $11 per dry ton for plants handling 100 to 1,000 dry tons of sludge per day, with chemical conditioning, and based on the 1972 dollar.

Vacuum filtration almost always requires chemical conditioning of sludge, which constitutes a large portion of its operating costs. On the other hand, as compared to centrifugation, maintenance costs are lower. Also, while the initial costs of vacuum filtration are comparatively lower, these are partially offset by higher cost of power (Metcalf & Eddy, Inc., 1972).

Vacuum filters present the same problems of plant nitrogen buildup as the aforementioned processes. In addition, vacuum filters present a greater odor problem, but a lesser noise problem, than centrifuges.

B. SLUDGE STABILIZATION SUBSYSTEMS

Sludge stabilization processes convert noxious and putrescible substances into stable products acceptable for final disposal. In some processes, such as incineration, reduction of sludge volume is accomplished simultaneously with sludge stabilization. Sludge can be stabilized by biological, physical and/or chemical methods. Among these methods, heated anaerobic digestion, Imhoff digestion, incineration, heat drying, and wet air oxidation are the most frequently used. Selection of a stablilization method depends upon the type and nature of the sludge, available pretreatment and final disposal alternatives, reliability and costs, energy conservation and other environmental considerations. Each of these five methods of stabilization is discussed in the following sections.

1. Heated Anaerobic Digestion

Anaerobic digestion can be defined as the biological decomposition of organic matter in the absence of molecular oxygen. This process can be accelerated by heating the sludge with combustion of digester gases. Decomposition is accomplished by gasification, liquifaction, stabilization, breakdown of colloidal structure, and release of moisture by a mixed culture of microorganisms. Two groups of microorganisms are predominantly responsible for the decomposition of organic material. The first group, which consists of facultative and anaerobic bacteria collectively called acid formers, hydrolyzes and ferments complex organic compounds into simple organic acids. The second group strictly consists of anaerobes called methane formers, which convert organic acids formed by the first group into methane gas and carbon dioxide.

In this digestion process, decomposition is not complete. Intermediate products of metabolism include organic acids, ammonia, methane, hydrogen sulfide, carbon dioxide, and carbonates. A 60 to 75% reduction in volatile solids is commonly achieved by anaerobic digestion, depending upon the initial volatile solids content of the sludge and the environment in the digesters. An environment which maintains a state of dynamic equilibrium between the acid formers and the methane formers is essential for optimal performance. Optimal environmental conditions are:

- 85 to 100°F (if the mesophilic or mid-range is selected)
- Strictly anaerobic conditions
- pH value between 6.6 and 7.6
- Good mixing of the sludge under digestion
- Sufficient biological nutrients
- Absence of toxic materials or inhibitors.

To attain mesophilic conditions in the digester, methane in the digester gases is utilized to heat the sludge. Sufficient digestion time is important for successful operation. When digestion is proceeding satisfactorily, alkalinity (as calcium carbonate) normally ranges between 1,000 and 5,000 mg/l, and the volatile acids are less than 250 mg/l (as acetic acid). Therefore, the performance of a digester is indicated by the pH value, alkalinity, volatile acids content, and volatile solids content of the digester effluent. High pH and alkalinity, as well as low volatile acids and volatile solids, indicate good performance.

Heated anaerobic digestion may compete in cost with mechanical dewatering and incineration. Digestion is a redundant process if sludge is eventually to be incinerated. In addition, sludge low in organic matter and high in toxic material, such as industrial sludge, is not suitable for digestion since it is toxic to bacteria.

Anaerobic digestion costs have been reported in many sources. Initial capital costs are approximately $2 to $2.50 per cubic foot of digester capacity. In the Chicago Sanitary District, total annual costs of digestion and lagooning of activated sludge with 3.5% solids are reported at $26 per dry ton (Lynam, et al., 1965); sludge thickening and digestion account for about 53% of these costs. Digestion costs vary widely with the degree of sludge concentration achieved by the preceding thickening process.

Burd (1968) conducted a literature review and reported that the cost of anaerobic digestion alone should be $5 to $18 per dry ton per year. A study conducted in Westchester County, New York, revealed that the capital cost for a standard-rate (low temperature) digestion system is about 2.5 times that for a high-rate (mesophilic) system of equal capacity. According to Stanley Consultants (1972), the total annual high-rate digestion costs, including capital, operation and maintenance amortized over 20 years at an interest rate of 7%, are approximately $8 per dry ton for a plant handling more than 500 dry tons of sludge daily (1972 dollars). The operating and maintenance costs for this plant size were $2 per dry ton per year.

Fuel gas produced by anaerobic digesters can be used to heat buildings and digesters, and sometimes for power production at the plant. The poor-quality supernatant liquid in the high-rate digester, which is pumped back to the head of the sewage treatment plant, frequently reduces overall treatment plant efficiency. This indirectly affects the environment of receiving streams.

Heated anaerobic digestion at the MSDGC West-Southwest plant brings about an 80 to 85% reduction of solids in the sludge. Most of the digested material is converted to water, carbon dioxide, methane, some hydrogen sulfide, and other gaseous compounds. These gases are burned to heat the digesters, and combustion products are released to the atmosphere. Most of these are water and carbon dioxide, but sulfur oxides and nitrogen oxides are also generated. The concentration of hydrogen sulfide may corrode heat-recovery equipment and require the use of a stack scrubber. Therefore, air pollution cannot be overlooked as a potential impact.

2. Imhoff Digestion

The Imhoff tank removes settleable and suspended solids by sedimentation, and liquifies, gasifies, and stabilizes the organic matter in the resulting sludge by bacterial digestion. All of these processes are accomplished in the same tank, without contaminating the settling sludge with products of sludge digestion (Beaumont, 1929). The tank is a two-story structure containing three compartments: the upper flow-through or sedimentation compartment; the lower sludge digestion chamber; and the gas vent and scum chamber which surrounds the upper compartment.

The sewage first flows through the upper compartment; solids settle to the sloping bottom, slide down, and pass through a slot which prevents the entrance of gas or digesting sludge in the lower section. The gas and rising sludge particles below are diverted to the gas vent and scum chamber. In a properly working tank, the gases generated should contain about 60 to 80% methane and 15% carbon dioxide. Digested sludge is drawn by pumps and is usually air-dried on sand beds.

Imhoff tanks provide sedimentation and sludge digestion in one unit and should produce a satisfactory effluent with 40 to 60% reduction of suspended solids and a 25 to 35% reduction in BOD, depending on sewage characteristics and retention time. With a 2 to 3-hour detention time in the sedimentation compartment, 100% removal of the settleable solids and 60% removal of the total suspended solids is quite common. Since the Imhoff tank has no mechanical parts, it is relatively easy and economical to operate. However, routine cleaning and maintenance of the tank are essential for successful operation.

Maintenance routines include daily removal of grease, scum, and floating solids from the sedimentation compartment; weekly scraping of the sides and sloping bottom of the sedimentation chamber is also necessary. Scum in the scum chamber must be broken up and removed if its depth attains 2 to 3 feet. Sludge must be removed from the digestion chamber before its level rises within 18 inches of the slot in the sedimentation compartment.

Foaming is a frequent problem associated with Imhoff digestion, especially in new tanks. Foaming is a result of poor digestion which can be caused by adverse sewage characteristics (e.g., toxic substances), temperature and pH value, all of which affect bacterial action. Foaming can be relieved by limiting, heating the tank during winter, chlorinating the influent sewage, cracking the scum to vent gas, and seeding the tank with well-digested sludge (Beaumont, 1929 and Murphy, 1931).

The operating and maintainance costs of Imhoff digestion are low except when chemicals such as lime or chlorine are used. Since the invention of separate mechanical clarifier and digestion units and the activated sludge process, the installation of Imhoff tanks has diminished. Construction or capital cost data are therefore generally unavailable. When the third battery of 36 Imhoff tanks was built in 1935 at Chicago's West Side Sewage Treatment Plant, the construction cost was $2,700,000 for a capacity of 204 MGD. Including the previous two batteries of tanks, the total capacity was estimated to be 472 MGD (Streeter, 1935). The capital cost was approximately $17,000 per MGD as compared to $28,000 per MGD for the then proposed Southwest Side Plant, an activated sludge plant with anaerobic digesters.

Environmental effects associated with Imhoff digestion are odors, attraction of flies, and possible risks of explosion. Chlorination of influent sewage and proper operation of Imhoff tanks can avoid most odor and fly problems. Collection of digestion gases and utilization for space heating or power generation can yield revenues while conserving energy. Explosions from the ignition of gas pockets in the Imhoff tanks or gas collection systems can be a serious hazard. However, explosions are rare if adequate safety precautions are taken. Some safety practices include isolation of gas lines, insulation of sources of ignition, routine investigation of leaks, and proper venting of gas accumulations (Nagel, 1941).

3. Incineration

Dewatered sludge cakes from vacuum filters and centrifuges can be sterilized and reduced in volume by incineration. Incineration destroys organic matter in the sludge and dewaters the sludge by evaporation. The two types of incinerators most applicable to sewage sludge are multiple hearth and fluidized bed incinerators.

The multiple hearth furnace consists of a circular steel shell surrounding a number of stacked-up solid refractory hearths. Partially dewatered sludge is continuously fed to the upper hearths, where the sludge is heated and vaporized at roughly 1,000^{o}F. Openings in each hearth allow sludge particles to crop to the next lower hearth. A high-temperature combustion zone between 1,600 and 1,800^{o}F is formed in the intermediate hearth, where volatile gases and solids are burned. The bottom hearth serves as a cooling zone. Fly ash is removed from the exhaust gases by wet scrubbers.

The fluidized bed incinerator consists of a combustion reactor or bed of fluidized sand which is supported by upward-moving air. Intimate contact between the sludge particles and oxygen is achieved by rapid mixing of the fluidized sand grains. Because of the large surface area provided by the sand particles, heat exchange between gases and solids is extremely rapid. Sludge is burned in the combustion zone at 1,400 to 1,500^{o}F. Auxiliary fuel is usually required when secondary sludge is burned. However, after start-up, dewatered raw primary sludge can be burned without this supplementary fuel. The residual ash particles are removed from the reactor by the upward movement of combustion gases. Ash partilces are removed from the gas phase by wet scrubbers.

From the study of a model city with 100,000 people contributing 2,530 tons of solids per year, the capital and operating costs for multiple hearth incineration are given in Table V-1. The total annual capital, operating and maintenance costs for a plant handling more than 500 dry tons of sludge per day are less than $15 per dry ton, based on the 1972 dollar (Stanley Consultants, 1972).

Table V-1. Annual Capital and Operating Costs for Multiple Hearth Incineration (Quirk, 1964)

(dollars per ton of dry solids)

	Incineration Without Deodorization	Incineration With Deodorization
Capital Cost	$ 9.15	$ 9.47
Operating Cost	$ 6.36	$ 9.50
Total Annual Costs	$15.51	$18.97

The annual capital and operating costs reported for fluidized bed incineration at Lynnwood, Washington, ranged from $26 to $35 for systems serving populations of 22,000 and 8,000, respectively (Alberston, 1965). At the East Cliff Sanitary District Plant, California, operating costs of approximately $25 per dry ton per year were reported (Sohr _et al._, 1965).

Variables in the cost of sludge incineration are:

- Nature of the sludge
- Amount and type of chemicals used in sludge conditioning before mechanical dewatering
- Degree of mechanical dewatering
- Costs of fuel, water and power
- Extent of air pollution control required
- Size and design of the treatment plant.

Environmental considerations for incineration are centered around air and water pollution. Air pollutant emissions include particulates, odors, sulfur oxides, nitrogen oxides, and volatile trace metals such as mercury. Wet scrubbers are efficient in removing fly ash but ineffective in capturing hazardous sub-micron particles (diameters between 0.1 and 1.0 millionth of a meter can lodge permanently in the lung). The wastewater from the scrubbers requires treatment to avoid water pollution problems.

Odor problems associated with incineration are of constant concern. Incomplete combustion or partial breakdown of organic volatile molecules is the major cause of odor. Maintaining an exit temperature of 1,200 to 1,500°F is effective in destroying odorants. This measure, however, requires auxiliary fuel and burners. Volatile trace metals which escape the scrubbers have some adverse impact on the environment. Economical means for removal of these emissions are not available. The relatively high fuel consumption for incineration, as opposed to other sludge processing methods, creates an impact on the environment and nonrenewable resources.

4. Heat Drying

Heat drying removes moisture from sludge, thereby providing for efficient incineration. Heat drying also prepares sludge for conversion into fertilizer. Drying is necessary in fertilizer manufacture to permit grinding and to reduce the weight of the sludge.

Dewatered sludge is mixed with dry sludge to reduce moisture content and particle size. The mixture is then fed into a flash drying system. In the system, sludge is passed through a high-temperature-and-turbulence zone for a few seconds, reducing the moisture content to approximately 10%. Heat-dried sludge is separated from the gaseous phase in a cyclone separator. Afterburners at a temperature of 1,400°F or higher are frequently required to deodorize stack emissions.

A study of the economic aspects of heat drying in a medium size plant, handling 2,530 dry tons per year, revealed that the annual capital and operating costs approximate $37 per dry ton with stack gas deodorization and $29 per dry ton without deodorization (Quirk, 1964). These costs do not account for the sale of dried sludge as fertilizer or as a soil conditioner.

Heat drying consumes more fuel than incineration processes. It also contributes to air pollution by emitting suspended particulates, nitrogen oxides, sulfur oxides and trace metals. However, heat drying has less air pollution potential than does conventional incineration, which requires higher combustion temperatures. Cost of air pollution abatement of exhaust gases can be substantial.

5. Wet Air Oxidation

The wet air oxidation process oxidizes sludge solids in an aqueous phase under heat and pressure. The commercialized application of the process has also been called the Zimmerman process or Zimpro. The system consists of a heater, compressor, storage tank, reactor, and liquid-and-solids separator. Ground, thickened sludge is preheated, pressurized and combined with pressurized air, and then introduced to the bottom of the reactor. Chemical oxidation of organic solids occurs as the mixture follows a baffled path through the reactor. Carbonaceous organic matter is oxidized to carbon dioxide and water, organic nitrogen compounds are converted to ammonia, and sulfur becomes sulfate. After oxidation, the residual ash is separated from the liquid phase.

Wet oxidation plant residues or ash are high in ammonia and volatile acids. The biological oxygen demand (BOD) in the process effluent varies between 5,400 and 8,400 ppm. The ash can be dewatered satisfactorily by vacuum filtration or centrifugation without chemical conditioning or aids Use of anionic polyelectrolytes certainly improves dewatering by centrifugation.

Data from Zimpro pilot-plant operations in the MSDGC indicated that 90% of the organic matter in sewage sludge can be oxidized at 500^{0}F and 1,200 psig (gage pressure). It was also concluded that if the feed solids concentration is high enough, sufficient thermal energy can be recovered to operate the entire wet oxidation process (Sanitary Engineering Committee Report, 1959).

The annual capital and operating costs of wet air oxidation in the MSDGC, providing a 70 to 80% reduction of chemical oxygen demand (COD), varied from $34 to $38 per dry ton of sludge (Ettelt and Kennedy, 1966). Operating costs for the Blind Brook Treatment Plant at Rye, New York were reported at $26.80 per dry ton (Harding and Griffin, 1965).

Failure of the wet air oxidation system can create severe occupational health hazards because the system is operated under more than 80 atmospheres of pressure. The process effluent, which is high in nitrogen, is recycled back to the head of the treatment plant. This causes nitrogen to accumulate in the plant, raising the nitrogen level in the plant effluent and reducing plant performance. The final consequence of this occurrence is an increased degradation of water quality in receiving streams. Accumulation of nitrogen after the introduction of wet air oxidation in the Chicago Sanitary District has been documented by Dalton and Murphy (1973).

C. SLUDGE DISPOSAL SUBSYSTEMS

In most cases, stabilized sludge is disposed of underground or on land. In areas where the ocean provides vast dilution capacity, it is the ultimate dumping site. The most frequently applied methods of sludge disposal are sanitary landfilling, lagooning, and ocean dumping. The operation of each, its reliability, unit cost, and environmental implications are discussed below.

1. Sanitary Landfill

The American Society of Civil Engineers defines sanitary landfill as:

> A method of disposing of refuse on land without creating nuisances or hazards to public health or safety, by utilizing the principles of engineering to confine the refuse to the smallest practical area, to reduce it to the smallest practical volume, and to cover it with a layer of earth at the conclusion of each day's operation, or at such more frequent intervals as may be necessary.

In a true sanitary landfill, waste are deposited in a designated area, compacted in place with a tractor or roller, and covered with 12 inches of clean soil.

Sanitary landfill can be used for disposal of sludge, grease and grit, stabilized or not, if a suitable site is available. The landfill is most beneficial if it is also used for disposal of refuse and other solid wastes. Liquid sludge acts as a wetting agent which increases compaction of the landfill; sludge cake or incineration ash mixed with refuse increases the density. Sanitary landfills can be divided into two major categories — area landfills, which are on relatively flat terrain, and depression landfills, which utilize natural or man-made depressions in the landscape such as a quarry or gravel pit.

Sanitary landfills have traditionally operated at low unit cost. Capital costs for a landfill include investment in land, site facilities, and equipment. A general capital cost cannot be estimated because of the wide variability in land prices. Annual operating costs for sanitary landfills were reported to vary between $0.50 and $2.00 per wet ton (Stone, 1962). These figures are very low compared to other landfill data. Therefore, overall costs are largely determined by hauling costs and land prices. Excluding land investment, the total capital, operating and maintenance costs are estimated to range downward from $1.80 to $1.20 per wet ton of sludge per year for operations of 1,000 to 10,000 wet tons per day, respectively (Stanley Consultants, 1972). Increased emphasis on environmental effects may elevate costs of sanitary landfills.

Poor management of sanitary landfills can result in adverse environmental effects. Dewatered sludge and other solid wastes in landfills degrade chemically and biologically to produce solid, liquid, and gaseous products. Microbiological decomposition of landfill material initially occurs aerobically, and then anaerobically when oxygen is depleted. Characteristic waste products of aerobic decomposition are carbon dioxide, water, nitrate, and nitrite. Migration or leaching of nitrate and nitrite can cause groundwater contamination. Typical products of anaerobic decomposition are methane, carbon dioxide, water, organic acids, nitrogen, ammonia, inorganic salts, and hydrogen sulfide. Some of these products are odorous. Acidic products can lower the pH value of the landfill and cause mobilization of trace metals which may affect the quality of surface and groundwater. Nuisance conditions such as odors and flies can be minimized with daily coverage of the waste, but cannot be avoided altogether.

In most areas, available land conveniently located is becoming increasingly scarce and old sanitary landfills are now being used for development. In general, this reuse was not contemplated during the construction of the original fill. Uneven settlement and poor bearing strength of fill materials present foundation problems which significantly increase construction costs. Total failure of structures built on landfill sites has been reported. Therefore, it may be desirable to build landfills so that future development can be undertaken at reasonable cost (Sowers, 1968).

2. Lagooning

Lagooning has been the most popular sludge disposal method for industrial wastewater treatment plants; lagoons are also used at municipal plants. Lagooning can be used as a contingency method of sludge handling and storage while other sludge processes are temporarily overloaded or out of service. Lagoons can be divided into three classes: thickening, storage, and digestion lagoons; drying lagoons; and permanent lagoons.

Digestion of sludge in the first type of lagoon is a lengthy process which creates multiple nuisance problems. Drying lagoons certainly compete with the use of sand drying beds. The sludge must be digested before entering the lagoon. Removal of dried sludge, which must be disposed of by other means, is necessary to maintain the effective capacity of a drying lagoon. Multiple units and supernatant decanting devices are required in the first two types of lagoons, as the supernatant is always returned to the head of the plant. A permanent lagoon, one from which the sludge is never removed, is an ultimate disposal site similar in function to sanitary landfills and has proven to be the most economical method of sludge disposal where suitable sites still exist.

Variables in lagooning operations are land availability, climate, subsoil permeability, groundwater table elevation, sludge characteristics, and sludge loading rates. Land available adjacent to the treatment plant substantially reduces sludge hauling costs. Good climatic conditions, which enhance evaporation of sludge water, are necessary for efficient performance. Soil permeability and groundwater elevation affect lagoon performance by determining the rate of drainage and the potential for groundwater contamination. Raw sludge generally requires less lagoon capacity than digested sludge. One cubic foot of lagoon can handle 6 lbs of raw sludge per year as compared to 2.3 lbs of digested sludge per year.

Construction costs of sewage stabilization ponds in the Midwest were reported to vary between $1,000 and $3,000 or more per acre. Lagoons constructed in depression areas can be significantly cheaper (Howells and Dubois, 1959). Excluding land investment, the construction costs of lagoons were estimated to range downward from $28.62 to $12.70 a year per acre-foot for lagoon capacities of 10 and 100 acre-feet, respectively. The costs are amortized using a 7% discount rate over 20 years and are based on the 1972 dollar (Stanley Consultants, 1972).

Literature reviews show that the operating and maintenance costs of sludge lagooning range from $1.00 to $3.50 per dry ton of sludge per year (Bubbis, 1962, Caron, 1964, Burd, 1968). In 1972 dollars, the annual operating and maintenance costs were reported by Stanley Consultants to be approximately $5.00 per dry ton for a plant producing 100 dry tons of sludge per day. Costs will increase if the sludge is transported long distances for lagooning.

Lagooning of raw sludge creates nuisance problems such as odor emission and insect infestation. Nuisance problems associated with lagooning of digested sludge are less severe. To minimize these problems, adequate buffer distances must be provided between the lagoons and the nearest sensitive receptors. Seepage and percolation of sludge water through permeable soil may present groundwater pollution problems. Lining the lagoon can prevent groundwater contamination, but this will increase both initial and operating costs; artifical drainage may be required due to loss of subsoil drainage.

3. Ocean Dumping

Ocean disposal of industrial and municipal sewage sludge has been commonly adopted by municipalities close to the sea. Some of the largest cities in the United States, including Boston, New York, Philadelphia, and Los Angeles, dispose of their sludge in this fashion. Ocean disposal has proven to be economical and effective as the ocean initially provides a 1,000 to 5,000-fold dilution. Barging of sludge to the ocean is considered to be economically justifiable where round-trip distances range up to 400 miles or more. Design and operating factors in ocean disposal are constrained by oceanic currents, mixing characteristics, and ebbing tides.

Of the two methods of ocean disposal — pipeline or barge, pipeline disposal is cheaper where transportation distance is short. For example, annual operating costs for the sludge outfall line at the Los Angeles Hyperion Plant were expected to be $1.15 per dry ton of sludge. New York City has been barging digested sludge 25 miles into the ocean for many years. By using larger and more mechanized barges and unloading sludge into the ocean more rapidly, New York City has been able to reduce sludge handling costs to $7.50 per dry ton (Burd, 1968). Philadelphia estimated barging costs to be $8.78 per dry ton of secondary sludge at 10% solids with a round trip travel distance of 227 miles (Baxter, 1959). The annual capital and operating costs of barging for the Blue Plains Treatment Plant at Washington, D.C., based on a 400-mile round trip, were estimated to be $17.95 per dry ton of sludge at 7.5% solids (Burd, 1968). A recent study of ocean disposal of digested sewage sludge having 10% solids revealed that costs of barging range downward from $0.32 per dry ton per mile for distances of 15 miles to $0.11 per dry ton per mile for distances of 150 miles or more (Shea and Stockton, 1975).

Ocean dumping of raw sludge is rare, because numerous nuisance problems result. Potential damage to marine environment and ecology resulting from ocean disposal of stabilized sludge has drawn increasing public concern. A Corps of Engineers study of the New York City sludge disposal grounds indicated that, because of high bacterial contamination in surf clams found adjacent to the disposal site, harvesting of clams should be prohibited within a 6-mile radium of its center (Smith and Brown, 1971). Of particular concern is the possibility that surf clams may accumulate and concentrate bacteria, viruses, and toxic substances found in sludge. These contaminants could, in turn, be biomagnified in food chains through consumption of the shellfish. Although ocean dumping is economically favorable for coastal communities, environmental effects must be taken into consideration, especially as regulations on ocean disposal become more stringent (Ocean Dumping Act).

D. SLUDGE UTILIZATION SUBSYSTEMS

Sludge utilization embraces the recovery of useful material from sewage sludge and recycling of sludge nutrients by fertilizing farm or forest lands, including the reclamation of mining spoil. Utilization of sludge is becoming more attractive and acceptable than disposal because it offers cheap substitutes for costly non-renewable resources while avoiding many of the increasing costs and environmental risks of disposal. Three methods of sludge utilization are recognized: fertilizer production, composting, and soil reclamation. Each method is reviewed below.

1. Fertilizer Production

Sewage sludge has been used as fertilizer and soil conditioner for many years. The use of liquid sludge has been rather limited because of handling difficulty, but dried sludge reduces this problem significantly. Preparation of these sludge products can be achieved by air drying on sand beds, mechanical dewatering, or heat drying, as discussed in Sections A. and B. of this chapter.

The value of sludge fertilizer is determined by nitrogen, carbon, phosphorous, and potassium contents. Hence, the value of sludge as a fertilizer is limited because of low concentrations of nitrogen, phosphoric acid, and potash. However, the high content of organic material in sewage sludge provides for excellent soil conditioning. The phosphorous content of municipal sewage sludge was significantly increased with the use of phosphate detergents (Anderson, 1956). Of course, this may not be as true currently because of the development of low-phosphate detergents. Of particular interest to agronomists is the carbon-nitrogen ratio of sewage sludge. A study of sludge characteristics in five municipalities indicated that the nitrogen content ranged from 2.0 to 6.0%; carbon 21 to 47%; phosphoric oxide 1.0 to 11%; ash content 24 to 53%; and humus 33 to 41% (Anderson, 1956). In general, digested sludge has a lower fertilizer value because the nitrogen content is reduced 40 to 50% by the digestion process.

In the past, many treatment plants with heat drying equipment converted from fertilizer production to sludge incineration or landfilling, because the sludge fertilizer market could not be successfully developed. This trend has been reversed recently because of the high-energy demands of incineration and the scarcity of landfill sites. Based on potential sales revenues and the concept of recycling nutrients, fertilizer production may gain more public acceptance. For example, Milwaukee, Chicago and Houston have successfully marketed large quantities of heat-dried activated sludge for many years. The price has depended on the nitrogen content of the sludge and has varied from $12 to $18 per ton (Burd, 1968). Over 200,000 tons each year were sold by these cities for application to crops, golf courses, and park land. However, most cities have donated sludge dried on sand beds in order to dispose of it off the plant site.

The major environmental concerns over the utilization of sludge as fertilizer or soil conditioner deal with possible health hazards from pathogenic microorganisms and trace metals and non-point source water pollution. Pathogenic microorganisms are destroyed by heat drying, but pathogens in air-dried or mechanically dewatered sludge might contact food plants or fodder and be ingested by humans or livestock. Trace metals such as zinc, nickel, copper, cadmium, lead, chromium, and mercury may be selectively concentrated or biomagnified through the food chain, presenting health problems to domestic animals and man.

Uncontrolled application of dried-sludge fertilizer may also contribute to non-point source water pollution, which is extremely difficult to confine and regulate. When assessing the benefits of stabilized sludge used as fertilizer, potential consequences to the environment must be weighed. Perhaps controlled distribution, mandatory sterilization, and limitation of dried-sludge fertilizer application to plant species having low rates of uptake and concentration of harmful substances would render this waste product safe enough. The costs of pre-treatment or advanced treatment of industrial wastewater, using carbon adsorption or other means to remove heavy metals, might be offset by the increased value of safe sludge fertilizer.

2. Composting

Composting is defined as the aerobic thermophilic decomposition of organic wastes to a relatively stable humus by microorganisms. The product of composting can be used as a soil conditioner. Traditionally, composting has been used to stabilize solid refuse. Sewage sludge has only occasionally been used in solid refuse composting. Composting systems generally fall into three categories: pile, windrow, and mechanized or enclosed systems.

Composting consists of three stages; namely mixing, composting and maturing. Solid refuse is sorted by screening and magnetic separation, and is pulverized in a grinder. Sewage sludge is then mixed with the pulverized refuse. The mixture is placed in windrows, pits, or silos for decomposition and stabilization. The compost row or pile is normally turned daily for 2 weeks or longer with a composter, except during periods of rain. Under proper composting conditions, temperatures in the windrow range from 130 to 150°F, falling into the thermophilic range wherein the rate of decomposition is the highest. The heat generated as a result of thermophilic microbial oxidation creates a convection current, supplying air to the microorganisms. High temperature also can provide for efficient destruction of pathogenic organisms and weed seeds. For efficient composting, the optimum pH of the material should be neutral.

After decomposition, the compost row or pile is flattened for further drying. Material removed from the composting system is cured for at least 30 days, which provides further stabilization. Besides solid refuse, other bulking agents such as sawdust, shredded paper, or wood chips can be used for sludge composting.

The Agricultural Research Service at Beltsville, Maryland, has studied sludge composting for several years. The capacity of the compost site is approximately 100 to 150 wet tons per day. Their experience suggests that the major problems associated with the operation are adverse weather conditions and odors. The study concluded that the annual capital and operating costs for composting 200 wet tons per day of digested sludge with 20% solids is approximately $7.31 per wet ton or $30.00 per dry ton of sludge. The operating cost alone accounts for $4.10 per wet ton or $16.80 per dry ton. Wood chips contribute over $2 per wet ton to the costs, most of which is for hauling. The cost estimate does not consider benefits from sale of the product (Epstein and Willson, 1974). Rodale and Scott reported that compost had been sold for $2.00 to $90.00 per ton (Burd, 1968). The smaller figure was the price of large quantities of raw compost; the large figure was the price for small specialty markets such as gardens and golf courses.

The environmental problems associated with composting are odors and attraction of insects. Odor nuisance seems to outweigh insect problems. If the compost system is too large, dense, or wet, anaerobic conditions may set in and produce undesirable odors. Enclosing the system is beneficial but increases costs. Distributing composting products as soil conditioners provides revenue, but may cause the same environmental problems as pertain to fertilizer production, discussed previously in this chapter.

3. Soil Reclamation

Application of liquid sludge to land is a practice dating back to antiquity, especially in England (Benarde, 1973). In the United States, disposal of sewage effluent or digested sludge on farmland has not been widely practiced, due partly to the past availability of inexpensive and conveniently handled inorganic fertilizer. However, higher costs and environmental risks with other methods of sludge disposal are making them less attractive. This fact prompts many wastewater management organizations to seriously consider the alternative of land application.

St. Mary's, Pennsylvania, has disposed of digested sludge on hay fields, pasture, corn stubble and athletic fields. The application rate for pasture is about 64 wet tons per acre per year with 3.7% solids. Raw sewage from Muskegon, Michigan is pumped to a series of aerated lagoons. The effluent from the lagoons, whose quality is equivalent to that from secondary treatment, is sprayed on farmland. The projected capacity of the system is 43.4 MGD, including an industrial flow of 24 MGD (Chaiken, Poloncsik, and Wilson, 1973).

Digested sludge has normally been utilized for land application, because raw primary and activated sludges decompose and create a nuisance. Liquid digested sludge can be applied to fields by spraying, soil incorporation, soil injection, ridge and furrow irrigation, and infiltration by shallow impoundment. Each method has specific advantages and disadvantages in terms of workability, reliability, and environmental effects. A detailed discussion is presented in Chapter VII. Transportation of sludge to the application site can be accomplished by tank truck, railroad tank car, enclosed barge, or pipeline, depending upon transport availability, site location, and cost-effectiveness. Detailed discussions of transportation are presented in the following section.

The rate of sludge application to land is determined by a number of factors, including climate, topography, hydrology, and soil and sludge characteristics. Literature review indicates that a wide range of application rates up to several hundred dry tons per acre per year have benefitted soil and crop growth (Table V-2). Upper limits are not yet recognized; ultimately they will be determined by the build-up of nutrients and heavy metals in the soils.

The economics of land application have not been fully investigated. The process recycles inexpensive and useful organic and inorganic materials back to the land, conserves non-renewable resources such as inorganic fertilizers, and eliminates costly sludge thickening and dewatering. The capital costs for land application include land

Table V-2. Digested Sludge Application Rates (Burd, 1968; Ewing and Dick, 1970)

Reference	Year	Type of Sludge	Approximate Solids Concentration (%)	Approximate Dry Solids Loading (ton/acre/yr.)	Remarks
Kershaw and Wood	1952	Digested primary and activated sludge	4.0	2.5*	England.
Merz	1955	Digested primary sludge	6.5	10-100	San Diego; 25 tons/acre equivalent to commercial fertilizer.
California State Water Pollution Control Boards	1957	Digested	--	100-300*	California; high to low rainfall areas, respectively.
Nusbaum and Cook	1960	Digested	--	1,000*	San Diego; land reclamation.
Wolfel	1964	Digested primary sludge	4.1	3.0*	Pennsylvania; well below commonly reported application rates.
--	--	Digested primary and activated sludge or trickling humus	--	2.0*	Nine Pennsylvania communities; well below commonly reported application rates.
Troemper	1965	Digested primary and activated sludge	6.0	61	Springfield, Illinois; average application rat
Hinesly and Sosewitz	1968	Digested	3.0	8-29*	Chicago; soybeans and corn responded favorabl

*No indication of annual repetition, so units may be ton/acre.

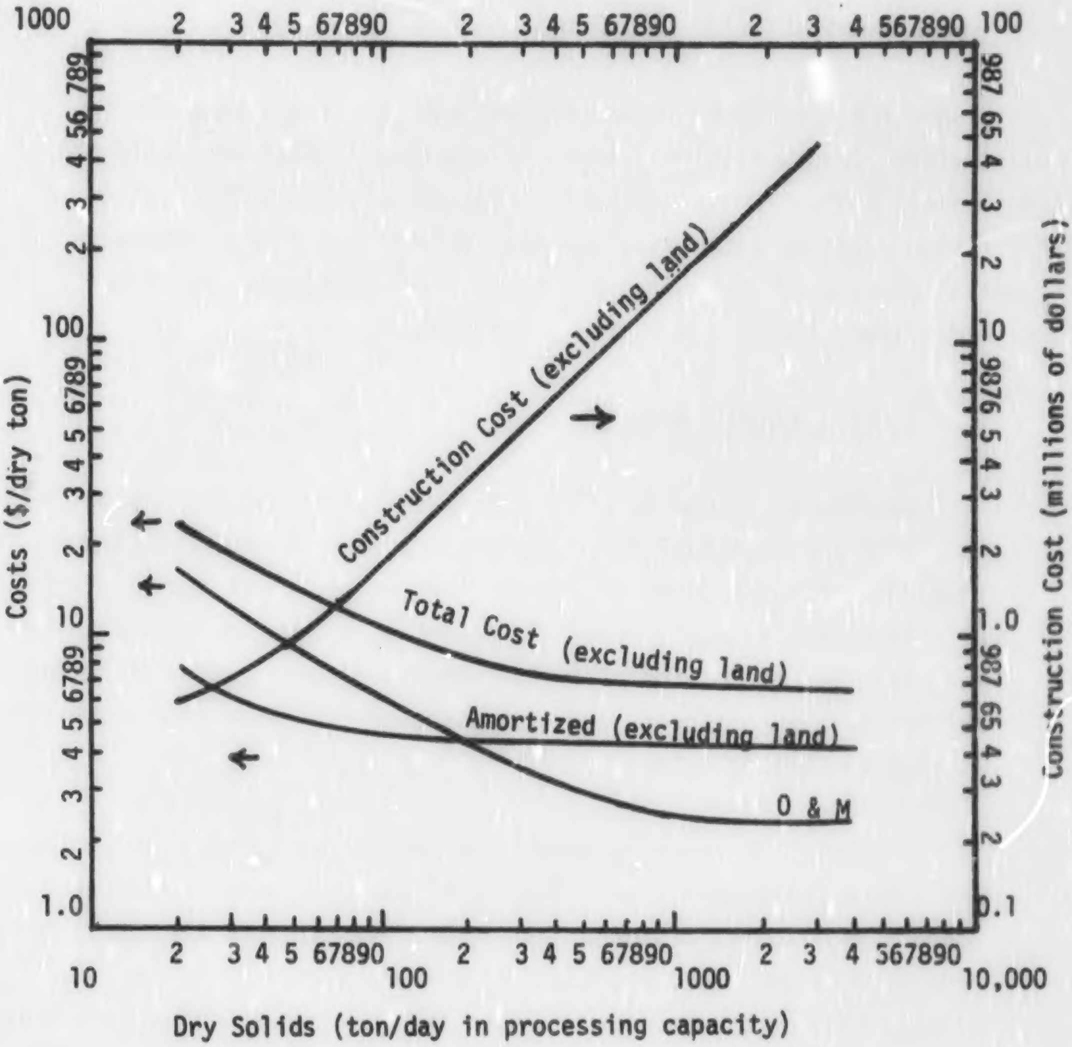
acquisition, access roads and fencing, site grading, sludge storage facilities, distribution systems, and application equipment. Operating costs include sludge transportation, sludge application and crop cultivation. Systems to monitor and control environmental effects further add to costs, and should be accounted for and weighed against those for other alternatives for sludge disposal or utilization. Table V-3 presents reported unit costs associated with land spreading of sludge.

The wide range in costs is due to the various hauling distances reported in each of the studies. The construction cost, amortized capital cost, operating and maintenance cost, and total costs excluding land amortized at 7% over 20 years are presented in Figure V-1, based on the 1972 dollar. For a project capacity of 1,000 dry tons per day, the total annual cost is approximately $7 per dry ton of sludge.

The major problem associated with land application is public acceptance. Potential environmental problems include transmission of odors and airborne pathogens, build-up of nutrients and heavy metals in the soils, surface water and groundwater contamination, and biomagnification of toxic substances in food chains or transfer of pathogens by ingestion, if agricultural produce is raised on the application fields. Proper choice and control of sludge application methods, rates and periods, and proper monitoring and pollution control should eliminate or minimize some of these environmental problems. A complete examination of potential adverse environmental and health effects and the available mitigating measures follows in Chapters VII and VIII and IX.

Table V-3. Land Spreading Costs (Burd, 1968; Dalton et al., 1968)

Reference	Year	Approximate Operating Cost ($/ton of dry solids)	Remarks
Scanlon	1957	$7.50	New York, about the same as barging to sea.
Nusbaum and Cook	1959-1960	$10.00	San Diego, 21-mile haul.
Nusbaum and Cook	1960	$4.00	San Diego, $1.50 for pipeline transfer.
Dalton et al.	1968	$20.00-23.00	Chicago Sanitary District preliminary estimate.
Burd	1968	$4.00-30.00	General range with $10/ton average.



Notes:

1. Minneapolis, March 1972, ENR Construction Cost Index of 1827.
2. Amortization at 7% for 20 years.
3. Labor rate of $6.25 per hour.
4. Application rate of 25 dry tons per acre per year.
5. Sludge diluted to a solids content of 2% for spray distribution.
6. Storage lagoons, dilution wells, pumping station, piping and spray distribution equipment included.

Figure V-1. Surface Spreading Costs (Stanley Consultants, 1972)

E. SLUDGE TRANSPORTATION SUBSYSTEMS

Sludge transportation is an integral part of sludge disposal or utilization. Transportation frequently exerts a significant influence upon overall costs. Optimization of sludge handling and disposal or utilization requires examination of the reliability, costs, and environmental effects of various sludge transportation modes. There are four modes identified: truck, rail, barge, and pipeline.

1. Truck Transportation

Hauling of sludge by truck offers the advantage of flexibility in routes and destinations. Liquid sludge can be hauled by trucks from one treatment plant to another for further treatment or disposal. Dewatered sludge is commonly hauled by trucks to landfill sites for disposal, or to stockpiles for subsequent utilization as fertilizer and soil conditioner. Hauling distance can range from a few miles to several hundred miles.

Economics of trucking sludge are determined by hauling distances and sludge characteristics. Unit costs increase with increasing solids content and hauling distance. A comparative study of the costs of transporting 3.5% solids by pipeline, tank truck and railroad tank car indicates that truck transportation is the most economical mode for distances up to 150 miles and for a treatment plant size of approximately 1.5 MGD. Truck hauling costs per wet or dry ton of sludge are presented as a function of sludge hauling distances and solids content in Figure V-2.

The Blue Plains treatment plant in the District of Columbia in 1973 used its digested sludge for reclaiming marginal soils. Truck hauling and final disposal of sludge cake (20% solids) were handled by a private contractor at a cost of $6.85 per wet ton. In 1974, the contracted price was up to $8.25 per wet ton (Cassel and Mohr, 1974).

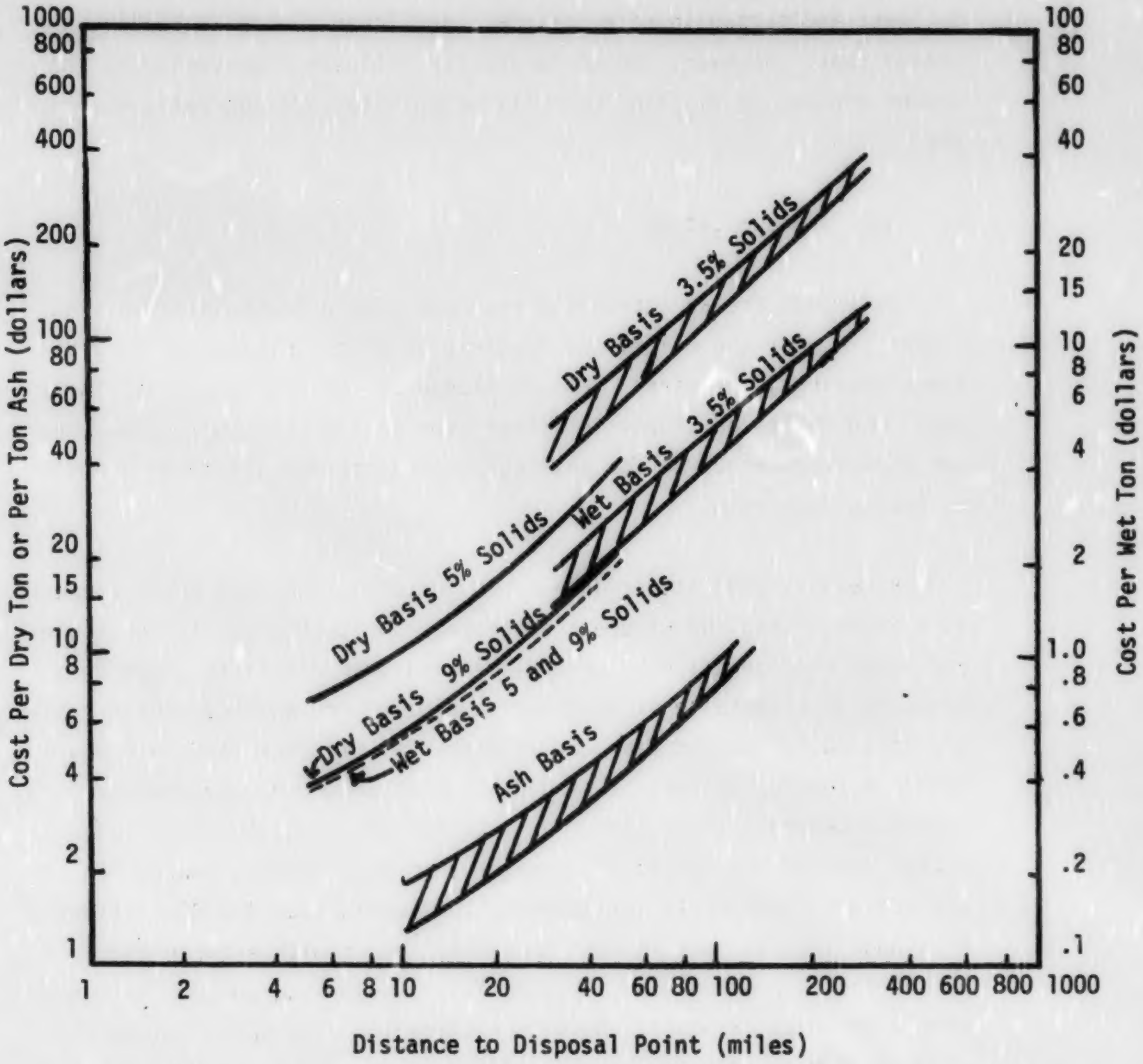


Figure V-2. Truck Costs (Riddell and Cormick, 1968; Stanley Consultants, 1972)

Health hazards and odor nuisance associated with sludge hauling by trucks are minimized by the use of special trucks with a sealed tailgate and tarpaulin cover or, in case liquid sludge is hauled, a sealed tank. However, the noise and air pollutants generated by the trucks enroute to disposal or utilization sites are generally unavoidable.

2. Rail Transportation

Railroads are an attractive mode for sludge transportation when tracks are near the origin and destination of the sludge and long distance hauling is required. Liquid sludge can be hauled by rail tank cars, and dewatered sludge in either open or closed hopper cars. Major structures required for railroad transportation are loading and unloading facilities.

Recently, some attention has been given to the unit train concept as a means of hauling sludge and refuse. The technology is available and under consideration by several metropolitan districts. The unit train in this instance might comprise 80 cars or vehicles. Each vehicle is a 20,000-gallon tank car with special fittings, and each can handle a load of 80 tons of sludge. The train could make journeys of several hundred miles. Indoor or outdoor systems could load sludge either through the top of the tank or through a loading connection at the bottom. Completely automated systems could load 400,000 gallons of sludge into 20 cars in less than 3 1/2 hours with a three-man crew. By increasing pumping rates, the facility could load 600,000 gallons of sludge in 2 1/2 hours. A two-man unloading crew could unload the sludge in approximately 2 hours. Based on a 200-mile journey, the 80-car unit train would have an overall turn-around time of 48 hours (Kostalich, 1973).

Based on a daily handling rate of 7,000 wet tons, the handling cost for a unit train would be less than $2.00 per ton of wet sludge containing 6% solids (Kostalich, 1973). The unit cost of hauling sludge by a regular train is higher and depends on the rate structures, which vary with geographic location. On reviewing the hauling contracts for Philadelphia and San Francisco, unit costs were found to be $5.39 per ton and $6.25 per ton, respectively. The former figure includes final disposal; the latter does not (Stanley Consultants). The unit cost per dry ton of sludge as a function of hauling distance is given in Figure V-3. For distances greater than 150 miles, rail transportation is more economical than trucking for treatment plants of 1.5 MGD. Generally, the cost of rail transportation could be reduced in half if the unit train concept were utilized (Easton, 1970).

The environmental hazards of hauling sludge by rail are similar to those for truck hauling. However, in the event of an accident, environmental impacts could be worse because of the vastly increased amount of sludge.

3. Barge Transportation

Barging of sludge must be considered as an alternative mode of shipping when navigable waterways are available between origin and destination. Large quantities of sludge can be transported efficiently, and often barges can be rented.

The costs of barging sludge are examined in the earlier section concerning ocean dumping. The cost of barging 250 miles from Washington, D.C. has been reported as $3.50 per wet ton (Smith, 1968). The barging of sludge 188 miles on the Illinois River from Chicago costs $1.80 per wet ton, based on a shipping rate of 9,000 tons per day (Stanley Consultants, 1972).

Environmental considerations in barging sludge are completely different from those for truck or rail hauling. Accidental spills of sludge from barges could cause severe short-term irreversible impacts such as a fish kill or destruction of local benthos. However, the probability of this occurring is small.

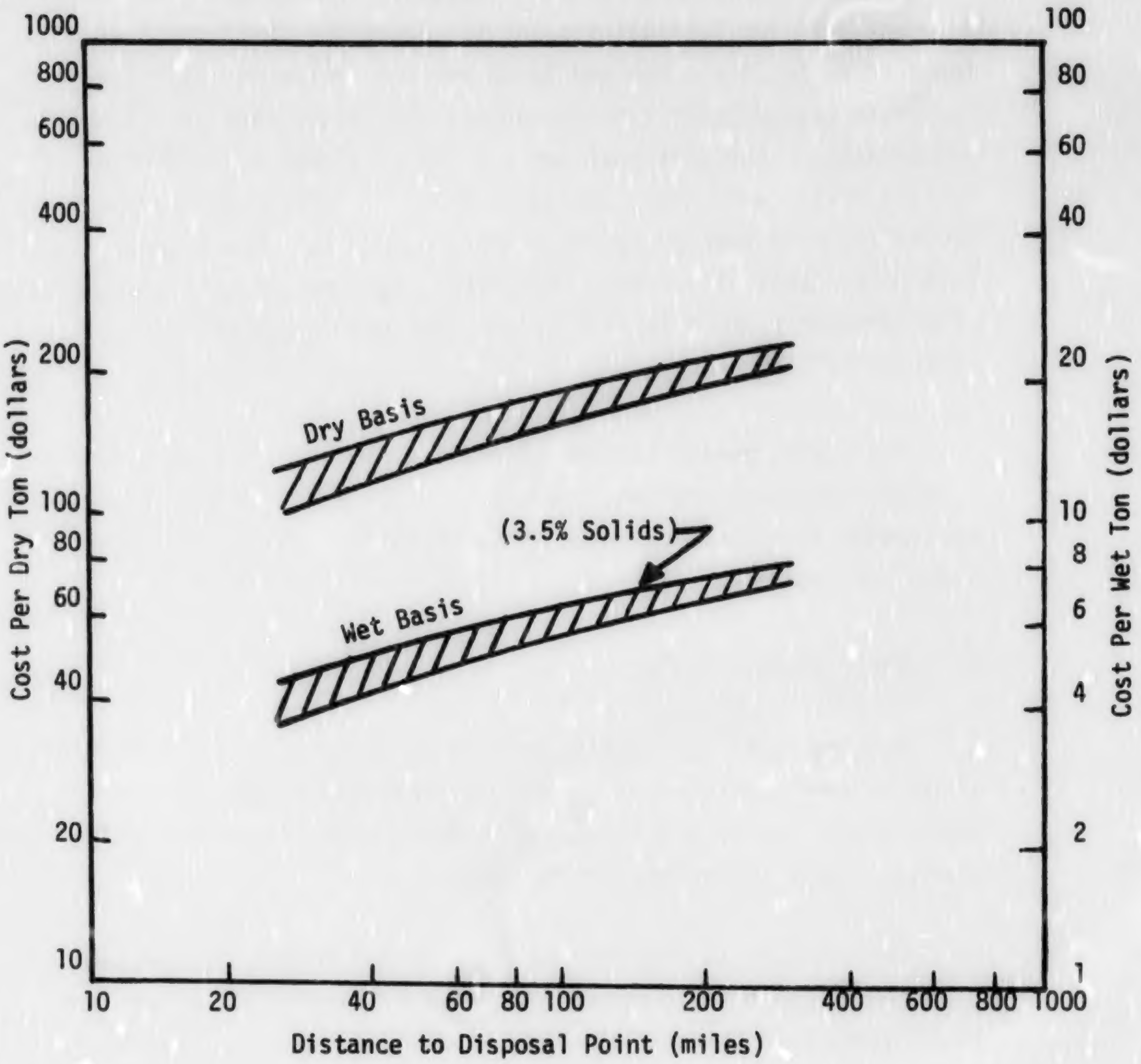


Figure V-3. Rail Costs (Riddell and Cormick, 1968; Stanley Consultants, 1972)

4. Pipeline Transportation

Pumping of sludge and waste slurries through pipelines has been practiced for many years. Short distance pumping of sludge exists in most sewage treatment plants. Transporting sludge through pipelines has also become a popular mode for intermediate and long distances.

When assessing this alternative, the main factor to consider is the hydraulic characteristics of the sludge. Sludge containing 5% solids flows as Newtonian liquid, which is similar to water with respect to friction and power requirements. Sludge with greater than 6% solids possesses plastic properties, requiring a prohibitive amount of energy for long distance pumping (Sparr, 1971). A minimum flow velocity must be maintained to prevent solids from settling and to sustain the flow during turbulence. Other problems associated with sludge pumping are grease build-up and pipe corrosion. Degreasing the sludge prior to pumping and installing protective pipe lining will avoid these problems.

A study was conducted to determine the feasibility of pumping sludge from Cleveland via a 92-mile, 12-inch diameter pipeline for disposal on strip-mined land in southern Ohio, and of pumping sludge from the Washington-Baltimore area 80 miles by pipeline to an ocean outfall (Bechtel Corporation, 1969). Capital and operating costs in the first case were estimated to be $25 per dry ton or $0.27 per ton-mile, assuming 3.5% digested solids. The costs in the latter case were estimated to be $28 per dry ton or $0.35 per ton-mile. Based on a population of 2,000,000, digested sludge with 5% solids could be pumped 100 miles at a cost of $7 or $8 per dry ton, or approximately $0.05 per ton-mile, to reclaim marginal or strip-mined land (Rand Development Corporation, 1967). These costs do not include acquisition of easements along pipeline routes. The use of pipelines does not become economical for transporting sludge 25 miles away until the plant size reaches approximately 10 MGD. A 300-mile pipeline cannot be economically justified until plant size reaches approximately 25 MGD (Riddell and Cormick, 1968).

Short-term environmental effects during pipeline construction include air pollution from traffic jams caused by the disruption or interference of traffic, especially in urban areas. Proper insulation of lift and booster stations will minimize noise impacts on surrounding areas.

F. COST-EFFECTIVENESS OF SYSTEM ALTERNATIVES

The evaluation of system alternatives for a proposed action is generally initiated by a review of existing facilities and their capacities, future planning periods and loading requirements, engineering considerations, and environmental and institutional constraints. Preliminary system alternatives are developed to represent a range of solutions sensitive to these considerations or constraints. The preliminary alternatives are then screened by cost analysis, reliability evaluation, environmental impact assessment, and estimate of compatibility with all significant constraints. During the evaluation process, new alternatives or revisions of preliminary alternatives may result.

In this section, current sludge processing and disposal systems are reviewed briefly as are the available and feasible methods for future processing and disposal. Compatible combinations of subsystems lead to the candidacy of ten system alternatives. System requirements and construction phasing, average annual capital, operating and maintenance costs, facility life, energy requirements, and environmental effects with their cost implications are discussed for each of the ten alternatives. By weighing each of these factors, a synthesis of comparative cost-effectiveness of the ten system alternatives is provided.

Existing sludge handling and disposal systems at the West-Southwest treatment plant, as well as present and future sludge production rates, are discussed in detail in Chapter II and are summarized below. Sludge dewatering subsystems in 1973 included air drying, sedimentation or flotation, and vacuum filtration. Stabilization subsystems available were heated anaerobic digestion, Imhoff digestion, heat drying, and wet air oxidation. Subsystems for disposal and utilization in 1973 included:

- Lagooning of liquid sludge after sludge concentration and anaerobic digestion
- Sale of dried sludge as fertilizer after sludge concentration, vacuum filtration, and heat drying
- Stockpiling and distribution as fertilizer after Imhoff digestion and air drying on sand beds

- Stockpiling of scum and grit
- Land application of liquid sludge after sludge concentration and anaerobic digestion
- Land application of liquid sludge after Imhoff digestion.

The wet air oxidation process has been on a standby basis since 1972.

The average sludge processing rate in 1973 was approximately 673 dry tons per day (MSDGC, 1975a). Based on an area population projection and assuming a planning period of 25 years beginning in 1975, the raw sludge forecast is 1,190 dry tons per day in the year 2000 (MSDGC, 1975a). This forecast includes 52 dry tons of sludge per day from the Northside plant.

Ten system alternatives for sludge processing and disposal were developed on the basis of experience gained from plant operations and research on various technical topics (MSDGC, 1973a, 1974a, 1974b, 1974c). Each system alternative has a planning period of 25 years, an average sludge production rate of 1,236 dry tons per day, and a maximum rate of 1,350 dry tons per day. Each alternative consists of a combination of several subsystems; namely, dewatering, stabilization, disposal and/or utilization and transportation subsystems. The system alternatives and sludge flows for each alternative are presented in Figure V-4. The costs, system requirements, construction phasing, and life of facilities for each system alternative are summarized in Table V-4 (MSDGC, 1975a).

1. System Requirements, Phasing, Costs, and Life

System 1 uses flotation-concentration of waste activated sludge, anaerobic digestion, centrifuge dewatering, and ultimate disposal of digested, dewatered sludge by sanitary landfilling. The system requirements and construction phasing are as follows:

- Seven 100-dry-ton-per-day digester batteries with concentration facilities constructed in 1975; four of the same constructed in 1980

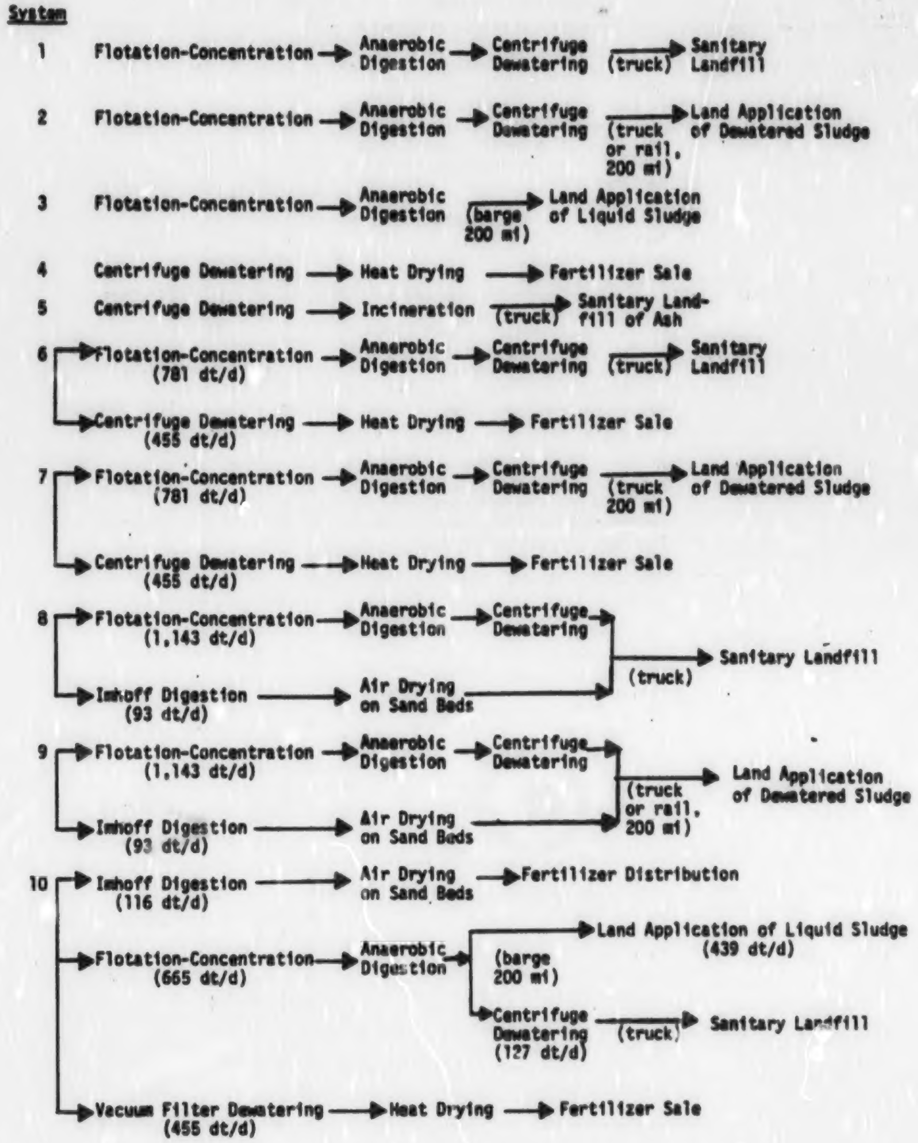

System
1
Flotation-Concentration
Anaerobic Digestion
Centrifuge Dewatering
(truck)
Sanitary Landfill
2
Flotation-Concentration
Anaerobic Digestion
Centrifuge Dewatering
(truck or rail, 200 mi)
Land Application of Dewatered Sludge
3
Flotation-Concentration
Anaerobic Digestion
(barge 200 mi)
Land Application of Liquid Sludge
4
Centrifuge Dewatering
Heat Drying
Fertilizer Sale
5
Centrifuge Dewatering
Incineration
(truck)
Sanitary Landfill of Ash
6
Flotation-Concentration (781 dt/d)
Anaerobic Digestion
Centrifuge Dewatering
(truck)
Sanitary Landfill
Centrifuge Dewatering (455 dt/d)
Heat Drying
Fertilizer Sale
7
Flotation-Concentration (781 dt/d)
Anaerobic Digestion
Centrifuge Dewatering
(truck 200 mi)
Land Application of Dewatered Sludge
Centrifuge Dewatering (455 dt/d)
Heat Drying
Fertilizer Sale
8
Flotation-Concentration (1,143 dt/d)
Anaerobic Digestion
Centrifuge Dewatering
Imhoff Digestion (93 dt/d)
Air Drying on Sand Beds
(truck)
Sanitary Landfill
9
Flotation-Concentration (1,143 dt/d)
Anaerobic Digestion
Centrifuge Dewatering
Imhoff Digestion (93 dt/d)
Air Drying on Sand Beds
(truck or rail, 200 mi)
Land Application of Dewatered Sludge
10
Imhoff Digestion (116 dt/d)
Air Drying on Sand Beds
Fertilizer Distribution
Flotation-Concentration (665 dt/d)
Anaerobic Digestion
(barge 200 mi)
Land Application of Liquid Sludge (439 dt/d)
Centrifuge Dewatering (127 dt/d)
(truck)
Sanitary Landfill
Vacuum Filter Dewatering (455 dt/d)
Heat Drying
Fertilizer Sale

Figure V-4. System Operations and Sludge Flows (MSDGC, 1975a)

Phasing, and Life of Facilities (MSDGC, 1975a)

System	Costs (10⁶ dollars/yr.) Amortized Capital ($)	O & M ($)	Total ($)	System Requirements and Constructin Phasing	1975	1980	1985	1990	1995	Life
1	5.62	26.05	31.67	7- 100 dt/d digester batteries with concentration facilities.	●					(25-yr.)
				4- 100 dt/d digester batteries with concentration facilities.		●				(25-yr.)
				37 - 21.9 dt/d centrifuges to supplement existing vacuum filtration facilities.	●		●		●	(10-yr.)
				10- 21.9 dt/d centrifuges.		●		●		(10-yr.)
				Additional 152 dt/d flotation-concentration facilities.						(20-yr.)
2	13.84	36.22	50.06* 47.70**	Same as System 1.	●	●	●	●	●	
				Land development (25,000 acres).	—	—	—	—	▶	(12.5-yr.)
				Application equipmnnt.	—	—	—	—	▶	
3	10.45	34.53	44.98	7- 100 dt/d digester batteries with concentration facilities.	●					(25-yr.)
				4- 100 dt/d digester batteries with concentration facilities.		●				(25-yr.)
				Land development (25,000 acres).	—	—	—	—	▶	
4	6.20	26.62	32.82	48- 21.9 dt/d centrifuges with flotation-concentration facilities.	●		●		●	(10-yr.)
				14- 21.9 dt/d centrifuges with flotation-concentration facilities.		●		●		(10-yr.)
				40- 12,000 lb water/hour drying lines.	●				●	(20-yr.)
				10- 12,000 lb water/hour drying lines.		●				
5	5.12	-22.71	22.83	48- 21.9 dt/d centrifuges with flotation-concentration facilities.	●		●		●	(10-yr.)
				14- 21.9 dt/d centrifuges with flotation-concentration facilities.		●		●		(10-yr.)
				10- 33.0 ft. diameter fluidized bed incineration units.	●		●		●	(25-yr.)
				102 dt/d ash dewatering centrifuges.						
6	4.95	23.82	28.77	6- 100 dt/d digester batteries with concentration facilities.	●	●				(25-yr.)
				57- 21.9 dt/d centrifuges.	●		●		●	(10-yr.)
				11- 21.9 dt/d centrifuges.		●		●		(10-yr.)
				19- 12,000 lb water/hour drying lines.	●				●	(20-yr.)
				Additional flotation-concentration facilities.	●					(25-yr.)
7	8.50	29.00	37.50	Same as System 6.	●	●	●	●	●	
				Land development (10,200 acres).	—	—	—	—	▶	(12.5-yr.)
				Application equipment.	—	—	—	—	▶	
8	5.74	25.78	31.52	Rehabilitation of Imhoff tanks and sand drying beds.	●					
				7- 100 dt/d digester batteries with concentration facilities.	●					(25-yr.)
				3- 100 dt/d digester batteries with concentration facilities.		●				(25-yr.)
				37- 21.9 dt/d centrifuges to supplement existing vacuum filtration facilities.	●		●		●	(10-yr.)
				10- 21.9 dt/d centrifuges.		●		●		(10-yr.)
				Additional 152 dt/d flotation-concentration facilities.						
9	13.96	35.95	49.91* 47.5[illegible]**	Same as System 8.	●	●	●	●	●	
				Land development (25,0[illegible] acres)	—	—	—	—	▶	
				Application equipment.	—	—	—	—	▶	(12.5-yr.)
10	3.75	31.4	35.19	3- 100 dt/d digester batteries with concentration facilities.	●					(25-yr.)
				2- 100 dt/d digester batteries with concentration facilities.		●				(25-yr.)
				27- 21.9 dt/d centrifuges.	●		●		●	(1[illegible]-yr.)
				Land purchase and development (2,700 acres).	—	—	—	—	▶	
				Application equipment.	—	—	—	—	▶	

*Assuming truck transportation.
**Assuming rail transportation.

- Thirty-seven 21.9-dry-ton-per-day centrifuges evenly scheduled for construction in 1975, 1985, and 1995, for the purpose of supplementing existing vacuum filtration facilities; ten additional centrifuges constructed between 1980 and 1990
- Additional 152-dry-ton-day flotation-concentration facilities.

The average annual capital, operating and maintenance, and total costs are \$5.62 x 10^6, \$26.05 x 10^6, and \$31.67 x 10^6, respectively (MSDGC, 1975a).

System 2 has the same sludge concentration,dewatering and stabilization processes as System 1, but disposes of digested, dewatered sludge by dry fertilizer application. Trucks will haul the dried sludge 200 miles to an application site. The system requirements include those of System 1 plus the development of 24,638 acres of land by the year 1995, and the necessary application equipment. The land development and equipment investment will be continuous over the planning period. Annual capital, operating and maintenance, and total costs are \$13.84 x 10^6, \$36.22 x 10^5, and \$50.06 x 10^6, respectively. If a railroad is used for sludge transportation, the total annual costs will be \$47.70 x 10^6 (MSDGC, 1975a).

System 3 utilizes the same concentration and stabilization processes as Systems 1 and 2, combined with ultimate disposal of digested liquid sludge by land application. The system requirements and construction phasing include seven 100-dry-ton-per-day digester batteries with concentration facilities constructed in 1975, and four of the same in 1980. There will be a continuous development through 1995 of 18,149 acres of land as an application site. Barging is the proposed sludge transportation mode. Annual capital, operating and maintenance, and total costs are \$10.45 x 10^6, \$34.53 x 10^6, and \$44.98 x 10^6, respectively (MSDGC, 1975a).

System 4 includes mechanical dewatering of sludge by centrifugation and stabilization of dewatered sludge by heat drying. The dried, stabilized sludge will be sold as fertilizer and soil conditioner. The system requirements and construction phasing are:

- 48 centrifuges with a capacity of 21.9 dry tons per day with flotation-concentration facilities, evenly scheduled for construction in 1975, 1985, and 1995, and 14 of the same between 1980 and 1990
- 20 drying lines with a capacity of 12,000 pounds of water per hour, constructed in 1975; 10 in 1980; 20 in 1995.

The amortized annual capital, operating and maintenance, and total costs are \$6.20 x 10^6, \$26.62 x 10^6, and \$32.82 x 10^6, respectively (MSDGC, 1975a).

System 5 includes mechanical dewatering of sludge by centrifugation, stabilization of dewatered sludge by incineration, and ultimate disposal by sanitary landfill. The system requirements and construction phasing include the same installations of centrifuges with flotation-concentration facilities as specified for System 4, plus:

- Ten 33.0-foot-diameter fluidized bed incineration units, constructed between 1975, 1985, and 1995
- 102-dry-ton-per-day ash dewatering centrifuges, constructed according to the same schedule as the incinerators.

The amortized annual capital, operating and maintenance, and total costs are \$5.12 x 10^6, \$22.71 x 10^6, and \$22.83 x 10^6, respectively (MSDGC, 1975a).

System 6 utilizes the operations of Systems 1 and 4 in parallel; the respective capacities, of course, are less. The system requirements and construction phasing are:

- Six 100-dry-ton-per-day digester batteries with concentration facilities, constructed between 1975 and 1980
- 57 centrifuges with a capacity of 21.9 dry tons per day each, constructed between 1975, 1985, and 1995

- 11 additional 21.9-dry-ton-per-day centrifuges between 1980 and 1990
- 19 drying lines with a capacity of 12,000 pounds of water per hour, scheduled between 1975 and 1995
- Additional flotation-concentration facilities at the beginning of the project.

The amortized annual capital, operating and maintenance and total costs are \$4.95 x 10^6, \$23.82 x 10^6, and \$28.77 x 10^6, respectively (MSDGC, 1975a).

System 7 is identical to System 6 except that sanitary landfilling of dewatered sludge is replaced by land application of the dried sludge. This substitution requires a continuous development of 10,200 acres of land by the year 1995, and requires investments in application equipment. The proposed transportation mode is trucking for the 200-mile journey to the application site. The annual amortized capital, operating and maintenance, and total costs are \$8.50 x 10^6, \$29.00 x 10^6, and \$37.50 x 10^6, respectively (MSDGC, 1975a).

System 8 utilizes existing Imhoff digestion, sand-bed air drying and sanitary landfilling in parallel with the same operations as in System 1. System requirements and construction phasing include:

- Total rehabilitation of Imhoff tanks and sand drying beds in 1975
- Seven 100-dry-ton-per-day digester batteries with concentration facilities constructed in 1975, and three of the same in 1980
- 37 centrifuges, each with a capacity of 21.9 dry tons per day, constructed between 1975, 1985, and 1995 in order to supplement existing vacuum filtration facilities, and 10 of the same constructed between 1980 and 1990
- Additional 152-dry-ton-per-day flotation-concentration facilities.

The amortized annual capital, operating and maintenance, and total costs are \$5.74 x 10^6, \$25.78 x 10^6, and \$31.52 x 10^6, respectively (MSDGC, 1975a).

System 9 is identical to System 8, except that sanitary landfilling of dewatered sludge is replaced by land application of the dried sludge. This substitution requires a continuous development of 24,638 acres of land by the year 1995, and requires investments in application equipment. Truck transportation to the application site 200 miles away is proposed. The amortized annual capital, operating and maintenance, and total costs are \$13.96 x 10^6, \$35.95 x 10^6, and \$49.91 x 10^6, respectively (MSDGC, 1975a).

System 10 is equivalent to Systems 3 and 6 in parallel, except for a substitution of vacuum filter dewatering in place of centrifugation before heat drying, plus another parallel sequence — Imhoff digestion, air drying on sand beds, and distribution as fertilizer. The system requirements and construction phasing are as follows:

- Three 100-dry-ton-per-day digester batteries with concentration facilities, constructed in 1975, and two of the same in 1980
- 27 centrifuges with a capacity of 21.9 dry tons per day, evenly scheduled for construction in 1975, 1985, and 1995
- Continuous purchase and development of 2,700 acres of land
- Necessary investment in application equipment.

The digested liquid sludge will be transported to the application site by barge. The amortized annual capital, operating and maintenance, and total costs are \$3.75 x 10^6, \$31.4 x 10^6, and \$35.19 x 10^6, respectively (MSDGC, 1975a).

2. Environmental Effects of Systems

In addition to costs, energy requirements, environmental effects, and system reliability must be considered in evaluating the cost-effectiveness of a system alternative. These factors are summarized in Table V-5 for each of the ten systems.

Table V-5. Potential Environmental Effects of System Alternatives (Enviro Control, Inc., 1975)

System Alternatives	Energy Requirements	Water Pollution Problems	Air Pollution Problems	Soil Contamination Problems	Necessary Mitigative Measures	Reliability Factors
1.	• Electricity for flotation and centrifuge units	• Surface and ground water pollution from landfill • Supernatant recycling from flotation and centrifuge units	• Odor and insect nuisance from landfill	• Contamination by toxic metals and organics, and by pathogens from landfilling	• Air and water monitoring • Underdrain the landfill site • Surface runoff controls	• Land availability for landfill
2.	• Electricity for flotation and centrifuge units • Diesel oil for truck fleet and land application equipment	• Surface and ground water pollution from land application of dewatered sludge • Supernatant recycling from flotation and centrifuge units	• Odor nuisance from spreading dewatered sludge on land • Emissions from trucks (400 mi. trip) • Noise of trucks	• Contamination by toxic metals and organics, and by pathogens from land application of dewatered sludge	• Air, water, and soil monitoring • Surface runoff controls • Control of application period and rate • Control of sludge quality • Control of truck emissions	• Land application is highly experimental • Vulnerable to fuel shortage for trucking
3.	• Electricity for flotation units • Diesel oil for sludge barging and land application equipment	• Surface and ground water pollution from land application of liquid sludge • Supernatant recycling from flotation units and sludge holding basins	• Odor nuisance from sludge holding basins • Odor nuisance and toxic or pathogenic substance from spraying sludge on land • Emissions from barge operation (400 mi. round trip)	• Contamination by toxic metals and organics, and by pathogens from land application of liquid sludge	• Air, water, and soil monitoring • Surface runoff controls • Control of application period and rate • Control of sludge quality • Covered or screened holding basins • Limitation on spray application	• Land application is highly experimental • Low sludge application rate requires a large amount of land

Table V-5. (continued)

System Alternatives	Energy Requirements	Water Pollution Problems	Air Pollution Problems	Soil Contamination Problems	Necessary Mitigative Measures	Reliability Factors
4.	• Electricity for centrifuge units • Gas or oil for heat drying units	• Pollution from non-point sources from fertilizer use • Supernatant recycling from centrifuge units	• Emissions from stacks of heat dryers	• Minor contamination	• Monitoring and removal of heat dryer emissions • Control of fertilizer uses	• Dependence upon fertilizer market development • Heat drying is vulnerable to fuel shortage and air quality regulations
5.	• Electricity for centrifuge units • Gas or oil for sludge incinerators	• Supernatant recycling from centrifuge units	• Emissions from stacks of incinerators	• Minor Contamination	• Monitoring and removal of incinerator stack emissions	• Incineration is vulnerable to fuel shortage and air quality regulations • Land availability for landfill
6.	• Electricity for flotation and centrifuge units • Gas or oil for heat drying units	• Pollution from non-point sources from fertilizer use • Supernatant recycling from flotation and centrifuge units	• Odor and insect nuisance from landfill • Emissions from stacks of heat dryers	• Contamination by toxic metals and organics, and pathogens from landfilling	• Air and water monitoring • Underdrain the landfill site • Surface runoff controls • Monitoring and removal of heat dryer emissions • Control of fertilizer uses	• Land availability for landfill • Dependence upon fertilizer market development • Heat drying is vulnerable to fuel shortage and air quality regulations
7.	• Electricity for flotation and centrifuge units • Diesel oil for truck fleet • Gas or oil for heat drying units	• Surface and ground water pollution from land application of dewatered sludge • Pollution from non-point sources from fertilizer use • Supernatant recycling from flotation and centrifuge units	• Odor nuisance from spreading dewatered sludge on land • Emissions from truck fleet (400 mi. round trip) • Emissions from stacks of heat dryers • Noise of trucks	• Contamination by toxic metals and organics, and by pathogens from land application of dewatered sludge	• Air, water, and soil monitoring • Surface runoff controls • Control of application period and rate • Control of sludge quality • Control of truck emissions • Monitoring and removal of heat dryer emissions • Control of fertilizer uses	• Land application is highly experimental • Vulnerable to fuel shortage for trucking • Dependence upon fertilizer market development • Heat drying is vulnerable to fuel shortage and air quality regulations

Table V-5. (continued)

System Alternatives	Energy Requirements	Water Pollution Problems	Air Pollution Problems	Soil Contamination Problems	Necessary Mitigative Measures	Reliability Factors
8.	• Electricity for flotation and centrifuge units	• Surface and ground water pollution from landfill • Supernatant or recycling from flotation and centrifuge units	• Odor and insect problems from landfill	• Contamination by toxic metals and organics, and by pathogens from landfilling	• Air and water monitoring • Underdrain the landfill site • Surface runoff controls	• Land availability per landfill
9.	• Electricity for flotation and centrifuge units • Diesel oil for truck fleet	• Surface and ground water pollution from land application of dewatered sludge • Supernatant recycling from flotation and centrifuge units	• Odor nuisance from spreading dewatered sludge on land • Emissions from truck fleet (400 mi. round trip) • Noise of trucks	• Contamination by toxic metals and organics, and by pathogens from land application of dewatered sludge	• Air, water, and soil monitoring • Surface runoff controls • Control of application period and rate • Control of sludge quality • Control of truck emissions	• Land application is highly experimental • Vulnerable to fuel shortage for trucking
10.	• Electricity for flotation, centrifuge, and vacuum filtration units • Diesel oil for barging • Gas or oil for heat drying units	• Surface and ground water contamination from land application of liquid sludge and landfill of dewatered sludge • Pollution from non-point sources from fertilizer use • Accidental sludge spills from barges • Supernatant recycling from flotation, centrifuge, and vacuum filtration units	• Odor nuisance from sludge holding basins • Odor nuisance and airborne toxic or pathogenic substances from spraying sludge on land • Odor nuisance from landfill • Emissions from barge operation (400 mi. round trip) • Emissions from heat dryers	• Contamination by toxic metals and organics, and by pathogens from landfilling and land application of liquid sludge	• Air and water monitoring • Underdrain the landfill site • Surface runoff controls • Air, water, and soil monitoring • Control of application period and rate • Control of sludge quality • Covered or screened holding basins • Limitation of spray application • Monitoring and removal of heat dryer emissions • Control of fertilizer uses	• Land availability for landfill • Land application is highly experimental • Low sludge application rate requires a large amount of land • Dependence upon fertilizer market development • Heat drying is vulnerable to fuel shortage and air quality regulations

The energy required by each system can be divided into three forms: electricity, gas, and oil. Because the costs presented for each system include allowances for energy consumption, only forms of energy and relative energy intensiveness are shown in Table V-5. The cost increment to a system resulting from future energy shortage is proportional to cost inflation for the energy source and the energy intensiveness of the system. However, future process changes permitting energy conversion such as from oil to coal may ameliorate rising energy cost.

The potential environmental effects considered for each system are classified into three major groups: air, water, and soil pollution. Air pollution problems involve emissions from incinerators, heat dryers, digesters, and from transportation sources; problems also occur from airborne toxic or pathogenic materials, odors and noise due to sludge processing, shipping and disposal. Water pollution problems include surface and groundwater contamination from sludge landfill and land application, and accidental sludge spills on waterways. Contamination of soil and associated vegetation may include the build-up of toxic metals or organic compounds and of pathogens from land application or landfilling.

To approximately equalize all systems in terms of environmental acceptability, measures to mitigate adverse effects are proposed for each alternative system, and are listed in Table V-5. Because the actual scale and costs of these mitigative measures are location specific, no dollar values can be designated at this stage of study. The last column of Table V-5 summarizes those factors limiting the feasibility and reliability of each system.

3. Summary of Cost-Effectiveness

As discussed previously, the cost-effectiveness of a system represents a balance primarily between monetary costs and environmental effects. The total annual costs of the ten system alternatives range from $\$27.83 \times 10^6$ to $\$50.06 \times 10^6$, as shown in Table V-6.

Table V-6. Ratings of Alternative Systems (Enviro Control, Inc., 1975)

Alternative	Total Annual Costs $(\times 10^6)$	System Reliability Limits	Potential Adverse Environmental Impact					Impact Mitigation Costs
			Energy Consumption	Air Pollution	Water Pollution	Soil Contamination	Composite Impact	
1	$31.67	Slight	Slight	Slight	Slight	Slight	Slight	Moderate
2	$50.06	Moderate	Moderate	Slight	Moderate	Substantial	Moderate	Substantial
3	$44.98	Substantial	Slight	Slight	Substantial	Substantial	Moderate	Substantial
4	$32.82	Substantial	Substantial	Substantial	Slight	Slight	Moderate	Substantial
5	$22.83	Moderate	Substantial	Substantial	Slight	Slight	Moderate	Substantial
6	$28.77	Moderate	Moderate	Moderate	Slight	Moderate	Moderate	Substantial
7	$37.50	Substantial	Moderate	Moderate	Moderate	Substantial	Moderate	Moderate
8	$31.52	Slight	Slight	Slight	Slight	Moderate	Moderate	Moderate
9	$49.91	Moderate	Slight	Slight	Moderate	Substantial	Slight	Moderate
10	$35.19	Substantial	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate

Composite environmental effects are evaluated by combining the energy, air, water and soil effects of a system alternative. Conceptually, this is carried out by summing up the magnitude of each environmental effect identified in Table V-5 for each system alternative. A ranking of system alternatives within each of the four environmental categories is presented in Table V-6, along with composite environmental rankings.

Finally, the end column of Table V-6 offers an estimate of the relative cost impact of implementing recommended mitigating measures (Table V-5). The purpose here is to reflect a general magnitude of costs, in addition to total annual costs, necessary to more or less equalize the environmental acceptability of alternative systems. The costs of conventional measures such as runoff controls are already reflected in total annual costs; therefore, the rough ranking of mitigation cost impacts covers only extraordinary features such as wet scrubbers for incinerator stacks.

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VI. SIGNIFICANT SOCIO-ECONOMIC AND LAND USE EFFECTS OF ALTERNATIVE ACTIONS

This chapter is devoted to an estimation of future uses of the land in the project area on the assumption that one or the other of two actions are carried out. The project either will be discontinued in its present state, leaving the land partially derelict and partially reclaimed, or will be continued and the land reused at some time in the future.

There are two steps involved in preparing these forecasts. First, it is necessary to predict the future socio-economic situation. In the first part of this chapter, socio-economic change affecting the environs of the project site is predicted on the basis of present socio-economic conditions reported in Chapter IV. These projections are then analyzed as to possible influences of project operation or discontinuance and of eventual land reuse in the project area.

The second major step is assessing future demand for various types of land use. In the second part of this chapter, future land use demand at the project site is predicted on the basis of socio-economic projections developed previously. Once the opportunities for particular land use are determined, the project area is analyzed to ascertain the physical constraints to accommodating such use. Again, physical capability is assessed under the two conditions of continued and discontinued sludge application.

For the purposes of this chapter, it is assumed that socio-economic and land use oppportunities are not constrained by possible environmental or health risks associated with either project implementation or abandonment.

A. POTENTIAL SOCIO-ECONOMIC CHANGE

Utilizing baseline information developed in previous chapters, this section deals with projecting trends in population, employment and income, land value, public finance, agricultural activity, mining and manufacturing, and retail and wholesale trade. These projections, once established, are then evaluated in terms of possible future influences by the project.

1. Population Change

Recent national rural-urban trends predict future population growth in areas such as Fulton County. These demographic trends include both historic trends and more recent factors which are expected to influence future trends. Past declines in agricultural and strip-mining employment have been instrumental in causing decline in the overall population of Fulton County and increases in the populations of Canton, Lewistown and Farmington. Expected future declines in agricultural and strip-mining employment will continue to affect the future population size and distribution.

More recent trends, such as the spread of industry to the exurban fringe of cities, will increase employment opportunity in many rural areas. Some of this manufacturing employment will encourage in-migration of skilled labor. Less-skilled labor can come from the existing rural labor force. Expansion of industry to the west and south of Peoria can be expected to enhance employment opportunities for the current residents of Fulton County and increase the in-migration of skilled laborers and their families.

A national survey has indicated that many city residents prefer nearby, or even remote, rural or small town residence to living in a large city (Beale, 1975). Considerable demographic data have shown that, since 1970, non-metropolitan areas are not only retaining people but are also receiving a net migration (Beale, 1975). Factors associated with migration to rural areas include the growth of state and community colleges and the development of rural recreation and retirement places, as well as the decentralization of manufacturing. Fulton County offers both recreational and retirement opportunities such as the Wee-Ma-Tuk Hills development adjoining the land reclamation project. Community colleges, such as the Spoon River Community College near Canton and adjacent to the project site, often cooperate with local businesses in providing appropriate skills for new enterprise.

This evidence clearly suggests that the population of Fulton County can be expected to grow. The major influences on the growth rate are the development of new manufacturing in Fulton and southwestern Peoria Counties and the accessibility of existing and potential residential areas to these manufacturing plants. When such factors affecting growth are considered, the total future population of Fulton County is expected to significantly exceed the population forecast by the Bureau of the Budget, State of Illinois. Future population is expected to be increasingly concentrated in Canton, Lewistown and Farmington. Substantial growth can also be expected in the northeastern quadrant of the County toward Peoria.

If the project is abandoned in its present state, current MSDGC employees would have to seek new employment. Manufacturing growth along the Illinois River should provide employment for many of the 120 seasonal employees working on the Prairie Plan project during 1975. Few of these employees can be expected to relocate their families. Most of the 23 permanent MSDGC employees would be expected to relocate their families outside of Fulton County.

Reclamation and reuse of the project area to produce crops or livestock would increase population only marginally, because it is estimated that 708 acres of pasture or 360 acres of row crops are needed to support one family (Schmitz, 1974 and Muehler, 1975). Conservation and recreation reuse would attract transient tourist populations.

2. Employment and Income

Continued declines in employment can be expected in the agricultural and mining sectors. These reflect the influence of advanced technology in replacing labor with capital-intensive methods of production. Such methods also necessitate increased training of the resident labor force or the importation of skilled labor. Even though the number of employees in agriculture and mining will decline, increasing skills will enhance average incomes.

Future employment in the service, wholesale and retail sectors will increasingly concentrate in larger towns. This urban orientation will be especially true for Canton, but will also influence Lewistown and Farmington. Employment in these sectors will be negatively influenced by declines in agriculture and mining, but possible small increases in manufacturing employment (mostly in new, small firms) and increases in agricultural and mining wages should offset this effect.

Under expected future conditions of higher labor mobility and increasing skills, the median income in Fulton County is expected to gradually converge with that of the U.S. (U.S. Water Resources Council, 1974). The higher average income and purchasing power in Fulton County should increase the strength of its service and trade activities. However, higher local wages combined with low unemployment is not especially attractive to new manufacturing, although the proximity of underutilized urban labor markets and higher labor mobility should enable a new manufacturer to import labor or attract commuters. Most of the new industries can be expected to have small labor requirements and to be tied to the production of metal and machinery.

The land purchased by MSDGC originally supported an estimated 37 full and part-time jobs, mostly held by local residents (Kelly, 1974). While these jobs were lost after the purchase, the increasing amount of agricultural land needed to support a farm worker indicates that, without the MSDGC purchases, the land in the project area would have supported progressively fewer workers. The increased number of jobs created by the Sanitary District absorbed approximately 120 skilled and unskilled contract laborers who average 6 to 8 months of employment yearly. Most of the skilled labor came from a multi-county region surrounding and including Fulton County, but most unskilled labor originated within Fulton

County. In 1975, the MSDGC paid approximately $890,000 to their contract employees. A rough estimate of the total salaries for the full-time staff of 23 is $300,000.

Discontinuing the project would result in income losses amounting to almost $1.2 million, as compared to a total county-wide personal income (in 1970) of about $100 million. It is difficult to closely estimate the multiplier effects of the job and income losses. Project abandonment would marginally affect the viability of a large number of jobs in local retail, wholesale and service enterprises. A reasonable multiplier for a rural county such as Fulton County is two (Fernstrom, 1974). Because many of the currently employed, skilled seasonal laborers live outside the county, the multiplied losses within the county would be somewhat less than twice the losses of salaries and wages.

Although no future date is projected, reclamation and reuse of the land would eventually displace MSDGC jobs and income, substituting less intensive economic activities. These probably would be limited by economic demand and land suitability to combinations of row crop farming, livestock production, fish and wildlife propagation, and unintensive recreation. These uses would generate little on-site employment and income. Visitors to the regionally attractive conservation or recreation sites created by the project would add some local income in tourist-related retail and service enterprises. However, poor access to the project area from larger population centers, due to distance and lack of a high-speed link, will limit this potential. Agricultural reuse, especially grazing, would have a small multiplier effect on local employment and income. Feedlots could contribute to the expansion of nearby meat packing firms.

3. Land Values

Future land values in the project area will be governed by the growth of Canton, competitive position in land speculation, and the economic intensity of future land uses. Expected future growth of Canton would slightly increase the value of all land within its geographic sphere of influence. Speculation in coal extraction and marketing might affect values in the project area should it become economically feasible to mine the thin seam of coal underlying the strip-mined surface layers.

The availability of competing land at least equally suitable for development is the major determinant of local land values. Large tracts of equally available and suitable land in Fulton County should keep land values low in the project area. Much of the project land is highly unsuited for building construction. Residential or industrial buildings may require expensive structural modifications where they are built on the disturbed unsettled soil of a strip-mined site.

In Land Use Survey of Strip Mines, Fulton County, Illinois, unreclaimed lands are defined as "areas where no attempt has been made to reclaim stripped land to a productive use." Using this definition, unreclaimed lands have been estimated to be worth $259 per acre or $64 per acre less than reclaimed strip-mined lands which are used productively (see Table IV-23, page IV-52). Land reclamation and re-use could, therefore, theoretically add about $152,450 to the market value of the 2,382 project acres of strip-mined land scheduled for sludge application (MSDGC Land Development Schedule, revised August 1974). For the period of sludge application, the 2,382 acres of stripped land and 1,000 acres of place land (formerly row-cropped), which comprise the current and planned sludge recycling fields, continue to be worth to the MSDGC the paid value of $378 an acre (Kelly, 1974).

4. Public Finance

Two major influences are expected to significantly improve the ability of Fulton County to attract and accommodate future growth, and thereby expand local public finance. One is the Central Illinois Light Company (CILCO) power plant, now nearing completion. Once the CILCO plant is operational, it is expected to more than double the total tax base of Fulton County (Sandberg, 1975). The expanded tax base is expected to yield the local revenues necessary to enhance public facilities and services so as to facilitate growth. The other influence is Federal and State funding of public works, such as the currently proposed road improvements between Peoria and Canton, which are expected to substantially improve the regional attractiveness of Fulton County.

Contributions of the reclamation project to local public finance would be minor as compared to the projected huge tax revenues from the CILCO plant and potential outside public funds for road or other improvements. Discontinuing the project will result in lost county revenues. In 1973, the MSDGC paid to Fulton County roughly $102,000 in real estate taxes and $34,000 in personal property taxes, most of which would be lost if the project is abandoned and the land is not reused. According to a statutory requirement, those formerly strip-mined portions of the project area would be assessed at rates applicable to their uses prior to strip mining. Other portions would be assessed as unproductive agricultural land.

Most feasible reuses of the land would produce much smaller public revenues than were gained from MSDGC tax payments. Even prime agricultural land in Fulton County (and very little of the project site can be considered as such) is assessed at only $380 to $570 (1975 estimates, Fulton County Tax Assessor). Public recreation or conservation uses would generate no tax revenues.

5. Agricultural Activity

The soils and topography of Fulton County, and of West-Central Illinois in general, are well suited for agriculture and support highly productive principal crops such as corn, soybeans, and hay. Future productivity of local agriculture will be influenced by the rich loess soils and the generally level topography, as well as by changing methods of agricultural production. Average farm size should increase while farming should continue to become more capital and less labor intensive, causing continued decrease in farm employment and population. At the same time, trends in farm production will increasingly favor the use of larger, more level fields and farms.

The impact of the project on agricultural activity in Fulton County hinges on the potential productivity of the 2,382 acres of formerly strip-mined land used for sludge disposal. It is assumed that sludge application to the 1,000 acres of place land will only marginally affect the productivity of these presently fertile fields. Other portions of the project area are only marginally suited to agricultural uses. Calculations based on 1970 data show an average annual return per acre from farmland in Fulton County of approximately $85 for row crops and $31 for pasture. Feedlots have a considerably higher return. This suggests an ultimate agricultural value added per year by the project of approximately $100,000 to $200,000 (1970 dollars) due to reclamation and agricultural reuse. (1969 data show a county-wide produce value of $33 million on commercial-sized farms, or farms with sales of over $2,500 per year.) These estimates of dollar return should be viewed only as crude indications of the potential lost value of agricultural productivity should the project be abandoned or full reclamation not be achieved. The values of agricultural production fluctuate considerably from year to year.

In its present state, land in the project area could be used primarily for grazing and row-cropping. However, without reclamation utilizing sewage sludge, any row-crop production on formerly strip-mined fields would depend on liberal applications of costly chemical fertilizers, extensive soil conditioning, and rigorous conservation practices such as crop rotation. Continued sludge application can be expected to enhance the nutrient and organic content of the soil considerably, and this would favor more intensive row-crop farming over the grazing of livestock.

6. Mining and Manufacturing

The future importance of strip mining in Fulton County may be determined by three factors:

- Increasing national consumption of coal for power generation
- Vertical integration of major coal consumers
- Large amounts of strippable reserves in Fulton County.

Increasing coal consumption, interacting with air pollution regulations, land reclamation requirements, and future improvements in sulfur removal from coal or coal combustion gases, will govern demand for high-sulfur coal such as exists locally. The vertical integration of major coal consumers, such as mine ownership and operation by a power company, would make large amounts of capital available for the continued mining of Fulton County's coal reserves. Previously unmined, yet strippable coal covers over 54% of the county (Griffin and Chicoine, 1974).

Clearly, the enormous reserves, the availability of capital for their extraction and increasing use of high-sulfur coal would exert great pressure to further exploit this resource. Nevertheless, coal mining is not likely to be a future land use in the project area itself. The remaining thin, deeper seams of coal below the project site are not nearly as well suited for future extraction as are other reserves nearby.

The major industrial firms in Fulton County are the International Harvester Company and the Central Illinois Light Company. Other large industries include J. C. Schaefer Electric, Inc. and Astoria Fibra Steel, Inc. Much of the influence of industry on local employment is applied by firms located in southwestern Peoria County. New industries would be more inclined to locate along the Illinois River than at the project site where road access is comparatively poor and cheaper water transportation for high bulk, low-value cargo is unavailable. The water supply at the project site is inadequate to support many industries, and low local unemployment rates indicate a low labor supply. Industrial location both along the river and at the site is favored by large land holdings, low land prices, available railroad transportation, close proximity to central markets, and the availability of coal.

The provision of internal access roads and the leveling of strip-mined areas have lowered construction costs for industrial buildings in the project area. However, wastewater disposal problems and highly mineralized water supplies discourage industrial development there. Also, unstable soils add significant costs and uncertainties to the construction of building foundations, hard-surface roads, rail spurs, and underground pipelines. Thus, the project site is neither physically nor economically adaptable for future manufacturing uses.

7. Retail and Wholesale Trade

Future retail and wholesale activities in and near Canton depend on the progress of road improvements. Non-neighborhood retail business and most wholesale activities in Canton could be affected adversely by increased accessibility of the Peoria market. Service activities should continue to increase in Fulton County, tempered by the location in Peoria of most highly specialized services.

Discontinuing the project would cause some temporary decline in the volume of local trade and services due to lost purchasing power of current employees of the MSDGC or its contractors. Reuse of the project land would affect trade and services only slightly since most expected reuse would be economically unintensive.

B. LAND USE OPPORTUNITIES AND CONSTRAINTS

The analysis of land use opportunities and constraints focuses upon the combined effects of socio-economic demand and physical land suitability on the future reuse of project land. Of course, land reuse is not assured by successful reclamation; there must be actual economic demand. Once demand by society is established, the available land must be physically capable of accommodating the desired land use.

On the basis of socio-economic projections, this section predicts future demands for agricultural, residential, and recreation or conservation land use. The project area is then evaluated for its physical capability to support these uses under two alternatives. Suitability is assessed under present conditions, assuming that sludge application is discontinued, leaving the land partially derelict and partially reclaimed. Then suitability is predicted, assuming the project is continued and the land fully reclaimed.

Sludge application fields which were formerly strip-mined (about 2,300 acres) would be marginally attractive for added row-crop farming. While the addition of nutrients and organic matter has been limited so far, the leveling of steep slopes, removal of large rock fragments from the surface, and the installation of erosion controls possibly make these fields adaptable to row crops.

Cattle grazing is not an economically competitive use in those areas which were formerly row-cropped. Growing pasture, however, would be a more likely alternative than row-cropping on the 2,382 acres of formerly strip-mined land. The major benefits from the project for pasture use are the leveling of strip-mine spoil and a slight addition of nutrients and organic materials. Leveling makes it possible to use farm machinery to control tree growth instead of hand labor which is prohibitive in cost. Small portions of the project area are well suited for the development of feedlots. Major on-site capability for feedlots has been provided by systems installed to control and monitor pollution from stormwater runoff. Such systems are necessary for environmentally sound management of feedlots.

1. Potential for Agricultural Uses

Present and future feasible uses for agricultural land in Fulton County include row cropping, pasture, feedlots, and forest management. Available information suggests that the future economic demand for increased amounts of farmland will be small. Besides shifting toward larger individual farms and increasing mechanization, local agriculture is changing its composition. Dairy, winter wheat and poultry production have declined, while corn, soybeans, swine, and beef cattle production have increased. Increases in beef and pork production have been encouraged by expanding local and regional meat packing facilities, notably Oscar Mayer. A trend toward feedlot production can be expected to be matched by increasing production of corn for feed.

Discontinuing the project and reusing the site would make available several thousand acres of land for row crops and pasture. Place lands, where sludge has been applied to former row-crop fields, are highly suited to renewed row-crop farming. Sewage sludge application has increased the nutrients and organic material in the soil, although not markedly at this early stage.

Steep slopes and severe problems of access in unreclaimed strip-mining areas have caused failure of previous local attempts to manage timber crops. The steep slopes of the strip-mined portions of the project area have been leveled and many access roads have already been built as a part of the MSDGC project. However, there would be a long time lag before the first timber harvest, and considerably more local land would have to be planted with trees to provide enough continuous supply to support a local lumber products industry.

Continued sludge application followed by reuse of the project site could have a major beneficial impact during the entire application period. The project could serve as the principal site in the U.S. for evaluating the effects of various application methods in different agricultural activities. The experiment would be highly valuable in assisting other comcolleges, such as the Spoon River Community College near Canton and adjacent to the project site, often cooperate with local businesses in providing appropriate skills for new enterprise.

This evidence clearly suggests that the population of Fulton County can be expected to grow. The major influences on the growth rate are the development of new manufacturing in Fulton and southwestern Peoria Counties and the accessibility of existing and potential residential areas to these manufacturing plants. When such factors affecting growth are considered, the total future population of Fulton County is expected to significantly exceed the population forecast by the Bureau of the Budget, State of Illinois. Future population is expected to be increasingly concentrated in Canton, Lewistown and Farmington. Substantial growth can also be expected in the northeastern quadrant of the County toward Peoria.

If the project is abandoned in its present state, current MSDGC employees would have to seek new employment. Manufacturing growth along the Illinois River should provide employment for many of the 120 seasonal employees working on the Prairie Plan project during 1975. Few of these employees can be expected to relocate their families. Most of the 23 permanent MSDGC employees would be expected to relocate their families outside of Fulton County.

Reclamation and reuse of the project area to produce crops or livestock would increase population only marginally, because it is estimated that 708 acres of pasture or 360 acres of row crops are needed to support one family (Schmitz, 1974 and Muehler, 1975). Conservation and recreation reuse would attract transient tourist populations.

2. Employment and Income

Continued declines in employment can be expected in the agricultural and mining sectors. These reflect the influence of advanced technology in replacing labor with capital-intensive methods of production. Such methods also necessitate increased training of the resident labor force or the importation of skilled labor. Even though the number of employees in agriculture and mining will decline, increasing skills will enhance average incomes.

Future employment in the service, wholesale and retail sectors will increasingly concentrate in larger towns. This urban orientation will be especially true for Canton, but will also influence Lewistown and Farmington. Employment in these sectors will be negatively influenced by declines in agriculture and mining, but possible small increases in manufacturing employment (mostly in new, small firms) and increases in agricultural and mining wages should offset this effect.

Under expected future conditions of higher labor mobility and increasing skills, the median income in Fulton County is expected to gradually converge with that of the U.S. (U.S. Water Resources Council, 1974). The higher average income and purchasing power in Fulton County should increase the strength of its service and trade activities. However, higher local wages combined with low unemployment is not especially attractive to new manufacturing, although the proximity of underutilized urban labor markets and higher labor mobility should enable a new manufacturer to import labor or attract commuters. Most of the new industries can be expected to have small labor requirements and to be tied to the production of metal and machinery.

The land purchased by MSDGC originally supported an estimated 37 full and part-time jobs, mostly held by local residents (Kelly, 1974). While these jobs were lost after the purchase, the increasing amount of agricultural land needed to support a farm worker indicates that, without the MSDGC purchases, the land in the project area would have supported progressively fewer workers. The increased number of jobs created by the Sanitary District absorbed approximately 120 skilled and unskilled contract laborers who average 6 to 8 months of employment yearly. Most of the skilled labor came from a multi-county region surrounding and including Fulton County, but most unskilled labor originated within Fulton to the cost of providing and maintaining pipelines and hard-surface roads. Despite such serious constraints, improvements made by the MSDGC to the formerly strip-mined portions of the project site have increased its suitability for residential use. These improvements do not, however, counter-balance the constraints which, together with the availability of numerous competing home sites throughout the county, make future residential development highly unlikely.

3. Potential for Recreation and Conservation Uses

Several factors directly concerning recreation are of major importance in an evaluation of impacts resulting under the action alternatives:

- Effects of generally poor accessibility on the use of regionally-oriented facilities
- Availability of areas nearby with recreation potential
- Deficiencies in locally-oriented recreation.

Poor accessibility will be a major limitation on the number of visitors to a recreation facility in the project area. Poor road conditions compound the difficulty in getting to the project site from interstate highways or major population centers. Of course, poor accessibility hinders but does not preclude large numbers of travelers. This is evidenced by more than 100,000 visitors last year to Dickson Mounds State Park and 100,000 visitors attending the four-day Spoon River Drive Fall Festival (Bordner, 1975; Shields, 1975).

The attractiveness of a regional recreation facility in the project area would be enhanced by the diverse attractions in nearby Spoon River Valley, along the Illinois River, at Dickson Mounds State Park, and in numerous formerly strip-mined areas. They are often used for hunting, fishing, camping, and driving off-the-road vehicles such as trailbikes and snowmobiles.

Probable recreation and conservation uses in the project area include hunting, fishing, camping, native prairie and wildlife and an outdoor ecology laboratory. The MSDGC's past and future alterations of the project site can be expected to exert important influences upon each of these activities. Continued sludge application would add organic material and mineral nutrients in quantities sufficient for the growth of a greater diversity of plant species than are normally found in unreclaimed strip-mined areas. Increased plant diversity generally leads to increased diversity in wildlife.

Former strip mines which are now sludge recycling fields have considerably increased capability for intensive or extensive recreation use. In particular, leveling steep slopes and removing surface rocks have decreased site limitations for playgrounds, campsites, recreation building sites, roads and trails. On the other hand, surficial materials are too clayey for high-traffic uses and for the assimilation of sanitary wastes.

Continued use of the project area for sludge disposal with eventual release of sites for recreation-conservation uses would have a major effect only in formerly strip-mined fields. There, the considerable enrichment of the nutrient and organic content of the soil can be expected to enhance the biomass of hunting, fishing and prairie conservation areas.

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VII. SIGNIFICANT ENVIRONMENTAL EFFECTS OF THE PROJECT

The purpose of this chapter is to assess the significant environmental effects associated with the project and to recommend mitigative or control measures. The chapter begins with a description of the characteristics of sewage sludge being applied to Fulton County fields. Sludge composition, by itself, suggests the potential for various environmental effects. The discussion of potential effects begins with the theoretical considerations in odor emission and detection, followed by the potential for airborne dispersal of odorants originating in the storage basins and those associated with alternative application methods. Potential contamination of ground and surface waters is assessed by comparing present water quality with the background conditions reported earlier. Possible soil contamination is evaluated next, and the chapter concludes with a description of noise effects associated with project operations. These categories of environmental impact are addressed in terms of general theoretical considerations, measurement techniques, potential and actual impacts, and measures to either prevent these impacts from occurring or to mitigate their unavoidable adverse effects.

A. QUALITY AND QUANTITY OF APPLIED SLUDGE

General sludge characteristics and environmental problems associated with sludge application are presented in Chapter II. However, the assessment of environmental impacts resulting from this particular project requires a description of the characteristics of sludge being spread on Fulton County fields. This section describes the sludge used in this project in terms of quality and quantity and concludes with a brief discussion of methods to control the quality of sludge before it is applied.

1. Sludge Quality

There are three types of sludges being shipped to Fulton County: sludge drawn from heated anaerobic digesters at the West-Southwest (WSW) treatment plant of the MSDGC; sludge taken from the Lawndale lagoons, except in winter when icing prevents removal; and mixtures of the two. Daily composite samples of sludge have been taken from the WSW plant loading dock and the Mannheim Road Terminal loading dock next to the Lawndale lagoons. The data on total solids, volatile solids and acids, and alkalinity are analyzed and plotted on logarithm-probability paper in Figures VII-1 through VII-4 for sludge originating from Lawndale lagoons and Figures VII-5 through VII-8 for sludge from the WSW plant digesters. Sludge drawn from WSW digesters is occasionally used to dilute sludge from Lawndale lagoons to improve pumping efficiency. Mixtures of plant and lagoon sludges are regarded as sludge from Lawndale since there are no data reflecting the mixture. In these figures, the frequencies of sludge constituent concentrations, such as total solids, volatile solids, volatile acids, or alkalinity, are given in percent. For example, if the frequency of occurrence of 4% total solids is 36%, then for 36% of the time the monitored sludge has a total solids concentration equal to or less than 4%. In other words, the sludge has total solids concentrations greater than 4% for 64% of the time.

If the plot assumes a straight line on logarithmic paper, the time-distribution of a sludge quality parameter is said to be logarithmically normal. Logarithmic normality of a data group can be analytically represented by two numbers: geometric mean and geometric standard deviation. The geometric mean represents the level of a sludge quality parameter above or below which the frequency of occurrence is 50%. Geometric standard deviation represents the spread of data points. A small geometric standard deviation means that all reported data values are close to the geometric mean value, or that sludge quality is relatively uniform. The representativeness of the geometric mean and geometric standard deviation for a group of sludge quality data depends upon the number of observations and the linearity of the log-probability plotting.

A rigorous mathematical analysis of available sludge quality data by skewed log-normal functions or other distribution functions was not attempted. Instead, Figures VII-1 through VII-8 show the geometric

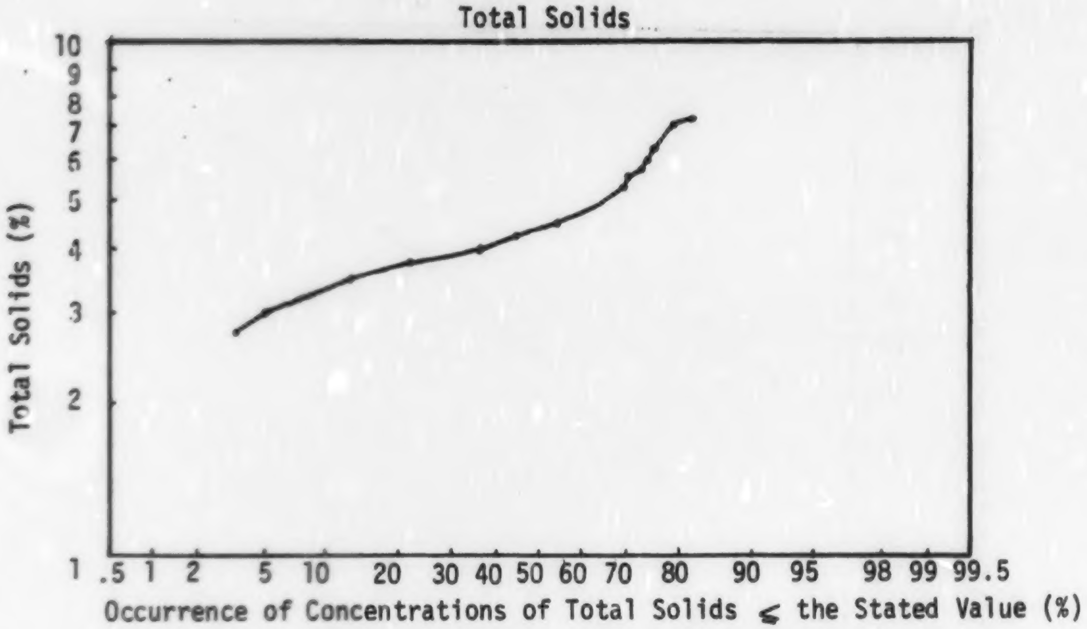

Total Solids

Figure VII-1. Total Solids Concentration in Sludge from the Lawndale Lagoons (MSDGC, 1972a through 1975g; Enviro Control Inc., 1975)

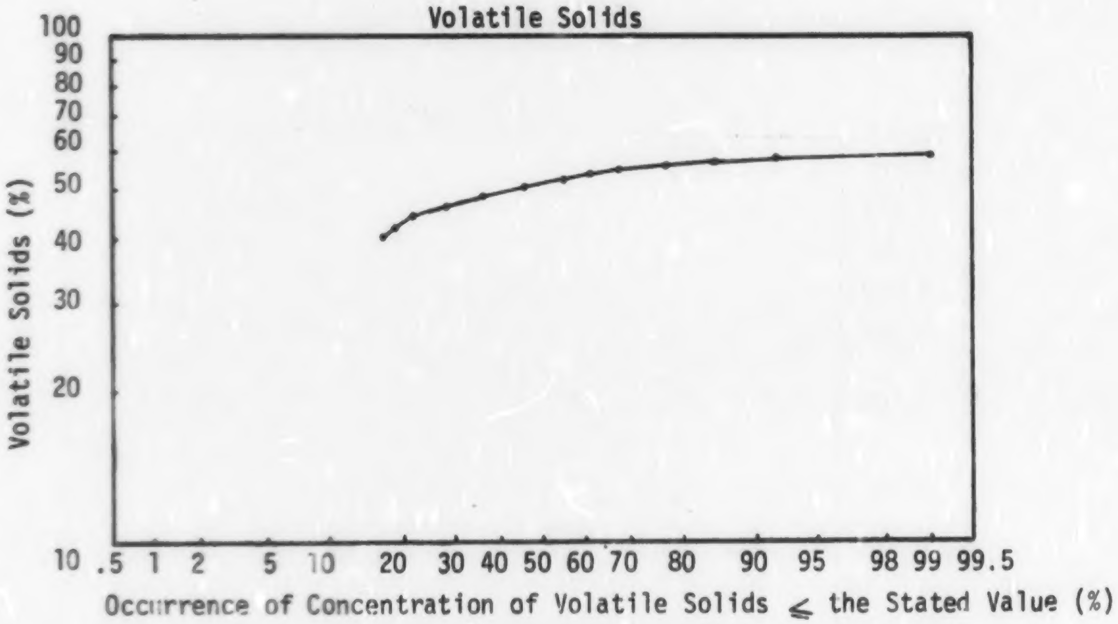

Volatile Solids

Figure VII-2. Volatile Solids Concentrations in Sludge from the Lawndale Lagoons (MSDGC, 1972a through 1975g; Enviro Control Inc., 1975)

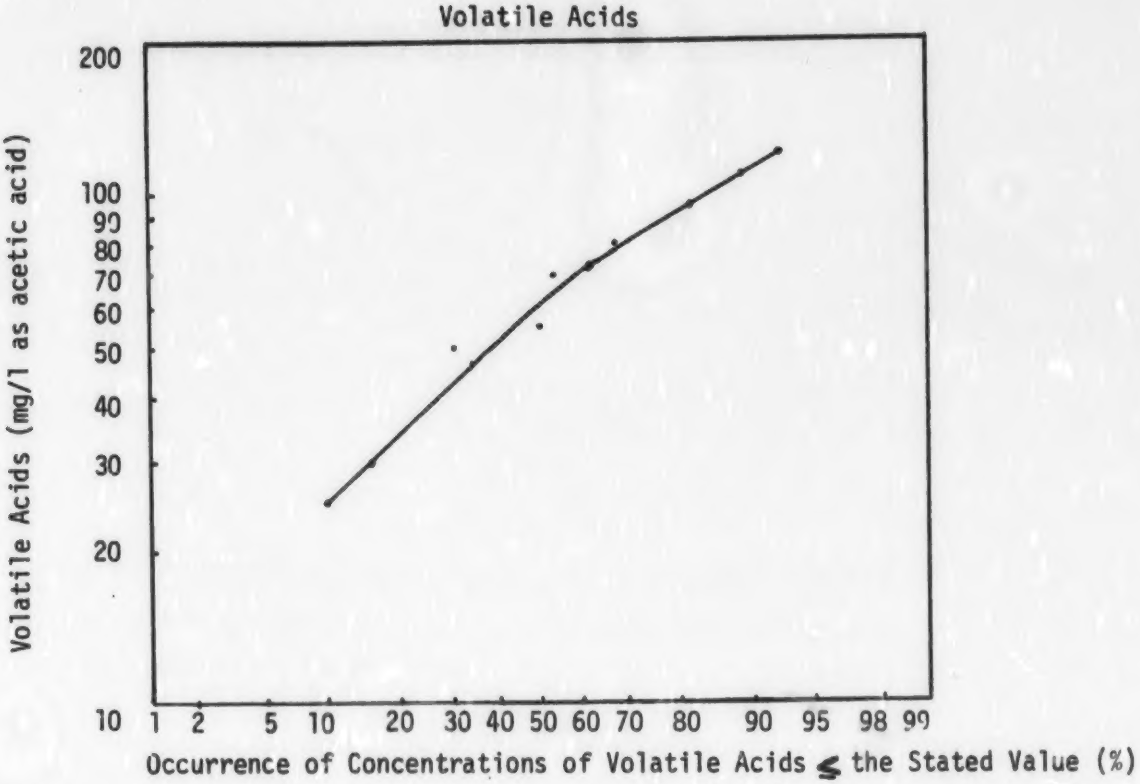


Figure VII-3. Volatile Acids Concentrations in Sludge from the Lawndale Lagoons (MSDGC, 1972a through 1975g; Enviro Control Inc., 1975)

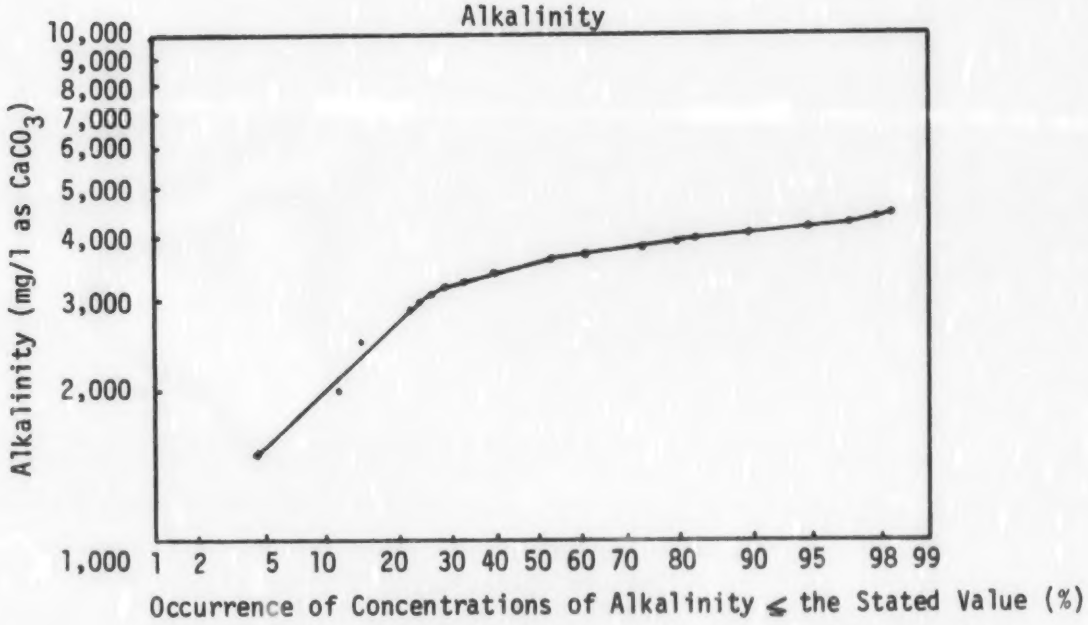


Figure VII-4. Alkalinity Concentrations in Sludge from the Lawndale Lagoons (MSDGC, 1972a through 1975g; Enviro Control Inc., 1975)

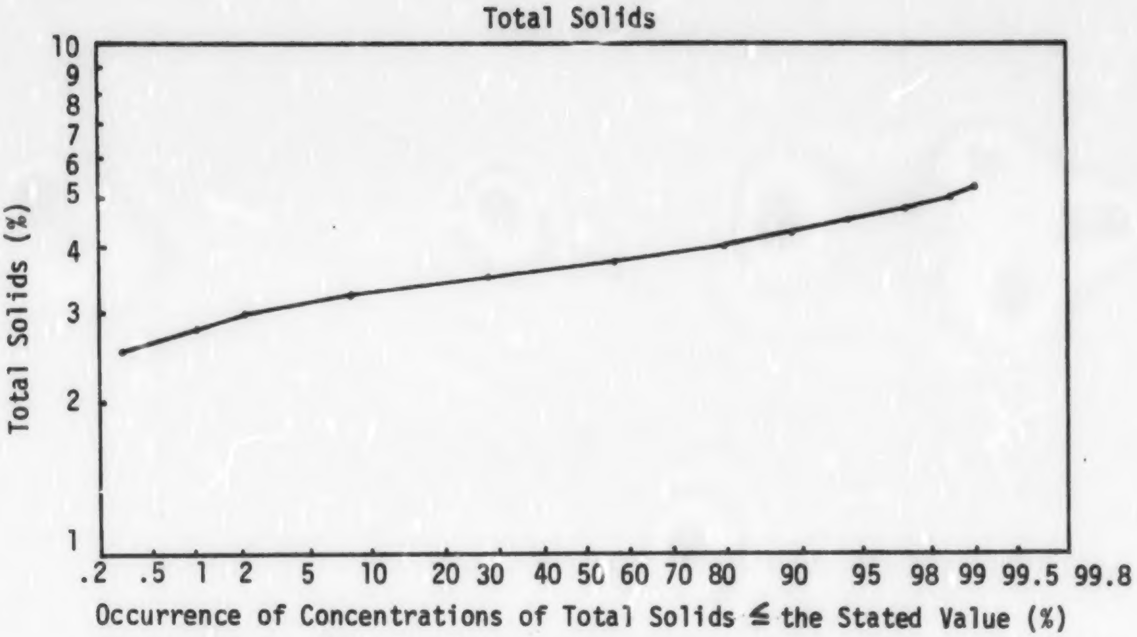


Figure VII-5. Total Solids Concentrations in Sludge from the WSW Plant (MSDGC, 1972a through 1975g; Enviro Control Inc., 1975)

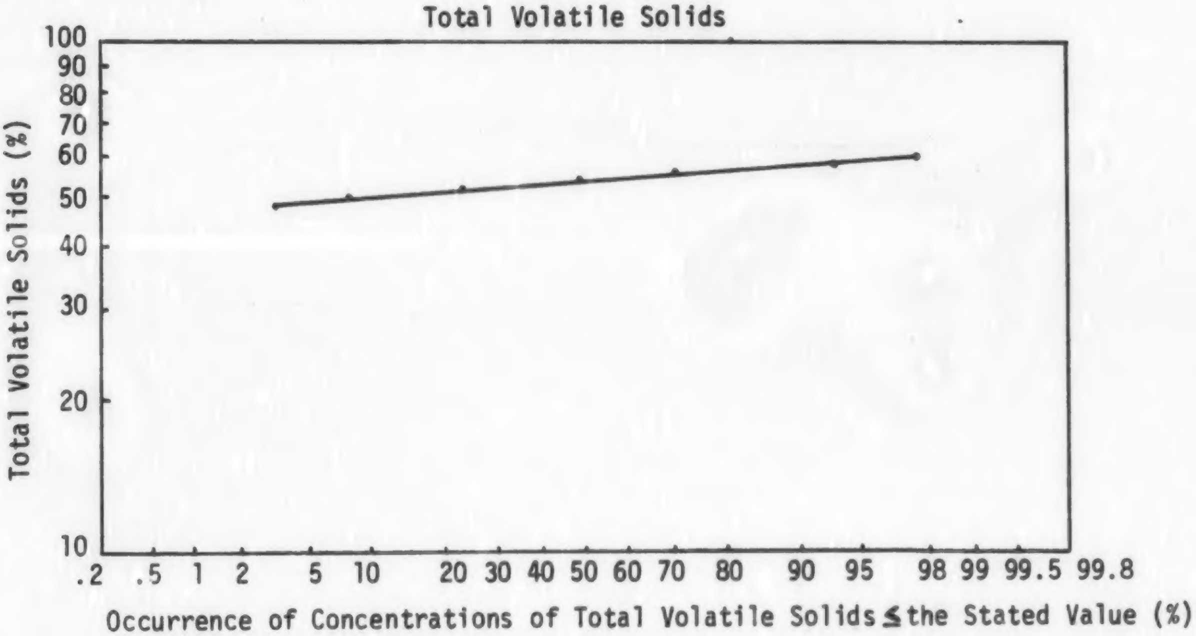


Figure VII-6. Total Volatile Solids Concentrations in Sludge from the WSW Plant (MSDGC, 1972a through 1975g; Enviro Control Inc., 1975)

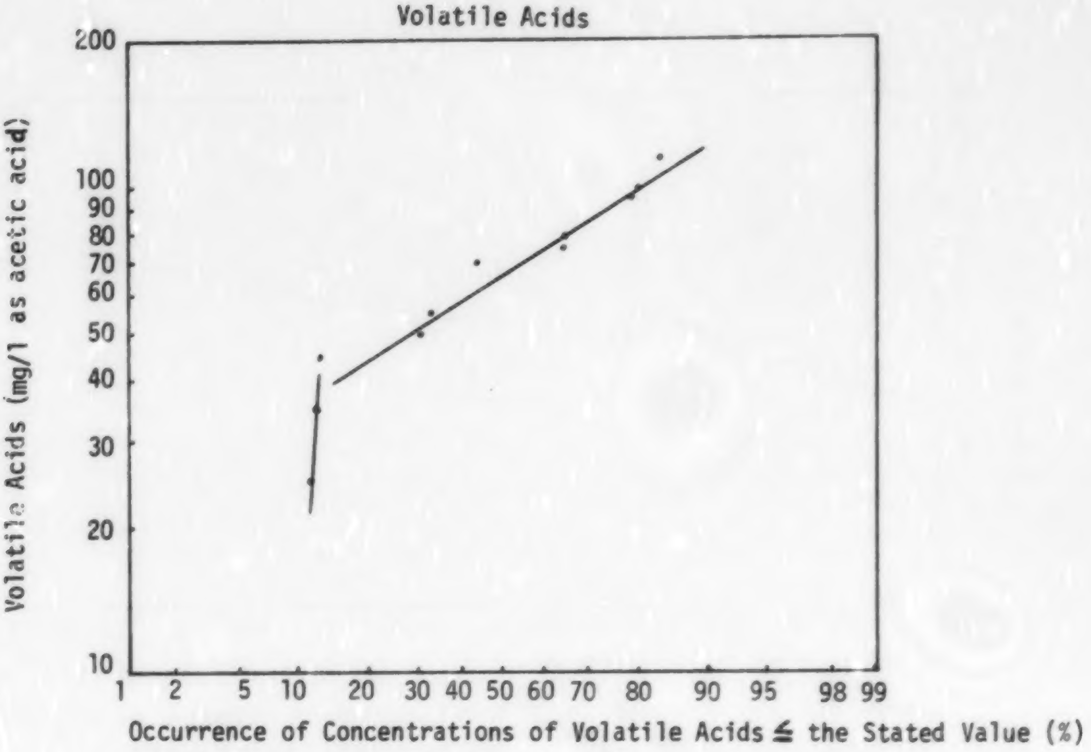


Figure VII-7. Volatile Acids Concentrations in Sludge from the WSW Plant (MSDGC, 1972 a through 1975 g; Enviro Control Inc., 1975)

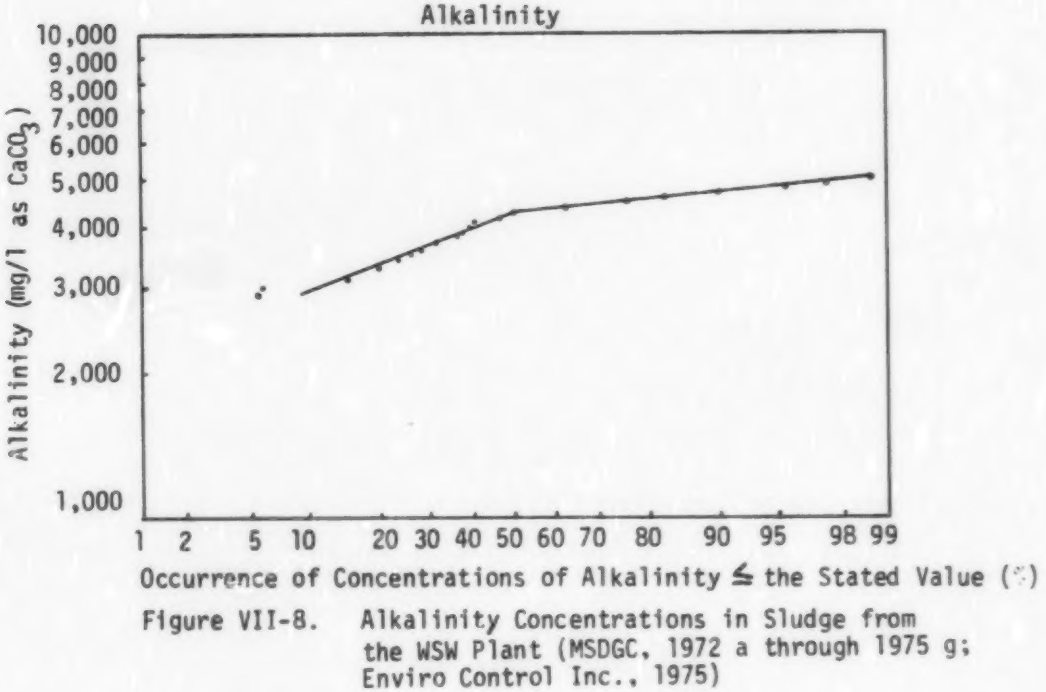


Figure VII-8. Alkalinity Concentrations in Sludge from the WSW Plant (MSDGC, 1972 a through 1975 g; Enviro Control Inc., 1975)

mean, geometric standard deviation, and number of observations, providing a general picture of the data spread or fluctuation. The plottings for volatile acids and alkalinity of sludges from both the WSW plant and Lawndale lagoons approximate two straight segments with a break point. Probably this is attributable to digester performance or to the different ages of sludge in the lagoons.

Properly digested sludge generally has high alkalinity and low volatile acids. Total solids and total volatile solids are less sensitive sludge quality indicators than are volatile acids or alkalinity. Sludge quality was compared with applicable sludge quality standards specified in the operating permit issued to the MSDGC. The applicable standards and the results of the comparative study are summarized in Table VII-1. In addition to the four parameters cited above, the pH value is included. Based on the length of the monitoring period, the number of samples, and the applicable standards, the number of violations permitted was calculated and indicated in Table VII-1. Compliance of sludge quality with applicable standards is determined by comparing the actual number of violations with the permissible number.

Sludge originating from the Lawndale lagoons has a generally higher quality than sludge from the WSW plant digesters, which is attributable to the aging of sludge in the lagoons. Sludge from the lagoons occasionally exceeds the standard for total alkalinity. Sludge drawn from the digesters is sometimes substandard in terms of total volatile solids, alkalinity, and/or pH. Violation frequencies are summarized below in Table VII-2.

Table VII-2. Compliance of Sludge Quality with Applicable Standards As of May 1975 (MSDGC, 1972a through 1975g; Enviro Control, Inc., 1976)

	Total Volatile Solids	Volatile Acids	Alkalinity	pH
Sludge from Lawndale Lagoons	Total compliance	Total compliance	Violated 9.5% of the time	Total compliance
Sludge from WSW Plant	Violated 3.8% of the time	Total compliance	Violated 1.4% of the time	Violated 1.3% of the time

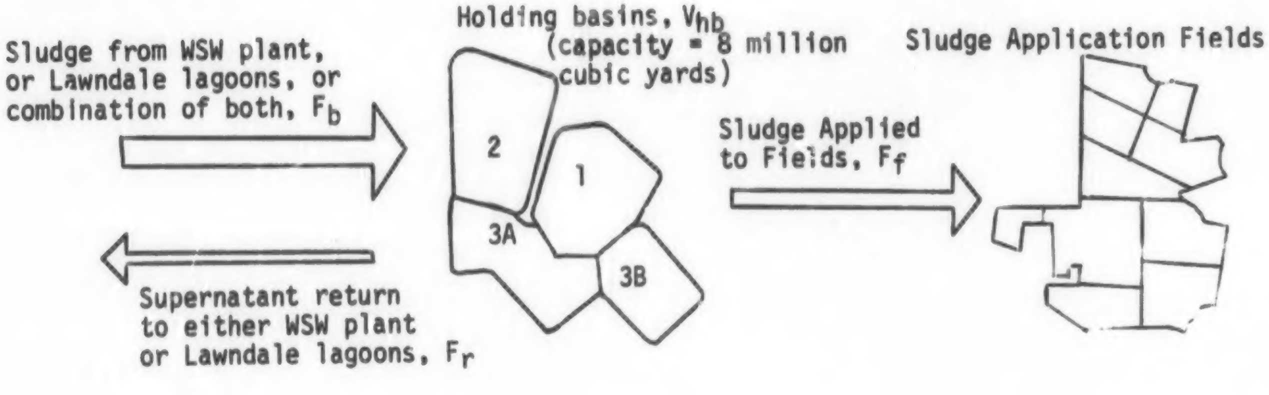
Table VII-1. Comparison of Sludge Characteristics With Applicable Sludge Quality Standards (MSDGC, 1972a through 1975g; Enviro Control, Inc., 1976)

Sludge Quality Parameter		Total Solids	Total Volatile Solids	Volatile Acids (as Acetic Acid)	Alkalinity (as $CaCO_3$)	pH
Applicable Sludge Quality Standards		Not Available	No 24-hr. composite sample may exceed 62% of total solids.	No more than five 24-hr. composite samples may exceed 300 mg/l in 30 days.	No more than 5% of the 24-hr. composite samples in 30 days may be lower than 2,500 mg/l.	No 24-hr. composite sample may be less than 6.9 units.
Sludge from Lawndale Lagoons	Number of Samples	147	130	69	137	141
	Geometric Mean	4.4%	51%	62 mg/l	3,800 mg/l	7.4(Arithmetic Mean)
	Geometric Standard Deviation	1.68	1.1	1.6	1.1	Not Applicable
	No. of Violations Permitted	Not Applicable	0	45	7	0
	Actual No. of Violations	Not Applicable	0	0	20	0
Sludge from WSW Plant	Number of Samples	396	367	241	222	394
	Geometric Mean	3.7%	54%	65 mg/l	4,200 mg/l	8.0(Arithmetic Mean)
	Geometric Standard Deviation	1.1	1.1	1.6	1.2	Not Applicable
	No. of Violations Permitted	Not Applicable	0	90	11	0
	Actual No. of Violations	Not Applicable	5	1	14	5

Sludge applied to the project fields is sampled at pumping stations, and its characteristics are summarized in Table VII-3. Because there are no standards designated for sludge applied to the fields, no comparative study was undertaken. In 1973, the total solids content of sludge applied to the fields in Fulton County ranged from 0.18 to 0.71%, which resembles the content of supernatant in the sludge holding basins. It follows, therefore, that supernatant was not mixed with the bottom sludge in the holding basins, and only the supernatant was applied to the fields in 1973. This is further supported by the consistently high pH values and low concentrations of total phosphorus, Kjeldahl nitrogen, ammonia nitrogen, cadmium, chromium, copper, lead, mercury and zinc which are associated with sludge particles.

2. Sludge Routes and Quantities

Sludges may originate from the WSW treatment plant or from the Lawndale lagoons, or combination from the two. These sludges are barged to the Liverpool dock and pumped to the four holding basins. A portion of the supernatant in the holding basins is occasionally barged back to either the WSW plant or to the Chicago Lawndale lagoons. During application seasons, sludge is pumped to various fields by a distribution system (see Figure VII-9 below).



Holding basins, V_{hb} (capacity = 8 million cubic yards)
Sludge from WSW plant, or Lawndale lagoons, or combination of both, F_b
Sludge Application Fields
Sludge Applied to Fields, F_f
2
1
3A
3B
Supernatant return to either WSW plant or Lawndale lagoons, F_r

Figure VII-9. Flow Diagram of Sludge

Table VII-3. Characteristics of Sludge Applied to the Project Fields (MSDGC, 1972a through 1975g; Enviro Control, Inc., 1975)

Sludge Quality Parameter / Month and Year	pH (unit)	Total Solids (%)	Total Phosphorus (mg/l)	Kjeldahl Nitrogen (mg/l)	Ammonia Nitrogen (mg/l)	Cd (mg/l)	Cr (mg/l)	Cu (mg/l)	Pb (mg/l)	Hg (µ/l)	K (mg/l)	Na (mg/l)	Zn (mg/l)
May and June, 1973	8.5	0.21	351	987	920	0.39	2.17	3.17	1.48	5.57	125	84.5	45
August, 1973	8.3	0.18	305	841	716	0.2	1.4	0.8	1.7	10.7	115	86	1.9
September, 1973	7.8	0.67	775	880	760	2.88	39.5	15.2	13.9	53.6	120	88	42.8
October, 1973	8.1	0.71	417	956	747	20	29.6	11.5	9.2	51.5	103	86	32.9
May, 1974	7.9	1.95	259	1,930	1,167	45.5	54	28.5	16	140	128	86	67.3
June, 1974	7.8	4.10	1,230	2,179	1,118	8.8	104	59.7	32	173	143	93	125
July, 1974	7.7	4.16	1,160	1,871	1,323	11.9	154	71.3	37	226	174	94	168
August, 1974	7.7	4.24	1,350	2,166	1,271	13.5	131	75.9	37	203	167	96	168
September, 1974	7.5	3.88	863	1,910	1,260	11.4	110	60.6	31	197	163	107	150
October, 1974	7.8	4.23	850	2,403	1,303	13.8	125	69.5	27	141	172	363	166
May, 1975	7.6	5.40	1,580	2,641	1,178	15.4	173	92.9	47	795	170	110	207

The amounts of barged sludge and supernatant are summarized in Table VII-4. The total sludge shipped to the holding basins amounted to 1,397.5 million gallons or 5.7 million net tons from April 1972 to May 1975. Supernatant return totaled 477.4 million gallons or 1.98 million wet tons during the same period. Based on the average total solids concentrations (see Table VII-3, page VII-10) and total wet tons of sludge applied to the project fields, the cumulative fluid volume of sludge applied is estimated to be 244.8 million gallons through an application period of 13 months, beginning in April 1972 and ending in May 1975.

The average sludge storage time in the holding basins can be estimated by a number of methods. Because the holding basins were never used at full capacity, a conservative method for estimating the average storage time is as follows:

$$t_s = \frac{F_b - F_r}{F_f} = \frac{(1397.5-477.4) \times 10^6 \text{ gal}}{(244.8 \times 10^6 \text{ gal/13 months})} = 49 \text{ months}$$

Where t_s = average storage time
F_b = sludge barged to the holding basins
F_r = supernatant returned to Chicago
and F_f = sludge applied to fields

This estimation is considered to be conservative because it does not account for loss of sludge water by evaporation. A storage time of 49 months is considerably long, and is a result of low sludge application rates during the development stages of the project

The application rate was originally proposed to be 70 dry tons per acre per year in the first year and taper down to 20 dt/acre/year in the fifth year of operations (Dalton and Murphy, 1973). These rates correspond to 726.5 and 207.6 million gallons of sludge, based on a 4% total solids content, applied to Fields #1 through #38, having a total area of 1,731.6 acres. Accordingly, the mean storage

Table VII-4. Amounts of Sludge and Supernatant Barged to and from the Holding Basins in Fulton County

PERIOD	Sludge Barged from:						Supernatant Returned to:			
	WSW Plant		Lawndale Lagoons		Both WSW & Lawndale		WSW Plant		Lawndale Lagoons	
	10^6 Gallons	Wet Tons	10^6 Gallons	Wet Tons	10^6 Gallons	Wet Tons	10^6 Gallons	Wet Tons	10^6 Gallons	Wet Tons
3rd Quarter, 1972	164.3	690,065	--	--	--	--	--	--	--	--
1st Quarter, 1973	137.5	577,427	--	--	--	--	--	--	--	--
2nd Quarter, 1973	145.5	611,309	--	--	--	--	--	--	--	--
3rd Quarter, 1973	69.1	149,230	1.53	6,427	--	--	2.08	8,746	--	--
4th Quarter, 1973	84.5	354,769	8.13	34,129	47.0	197,317	56.6	209,199	--	--
1st Quarter, 1974	132.7	557,279	--	--	--	--	30.0	126,750	--	--
2nd Quarter, 1974	147.1	617,810	5.08	21,321	--	--	87.4	366,808	--	--
3rd Quarter, 1974	72.0	302,561	6.82	28,650	63.8	268,147	64.6	271,139	6.75	28,360
4th Quarter, 1974	41.9	175,812	--	--	77.8	327,017	113.1	475,022	2.52	10,587
1st Quarter, 1975	114.1	479,189	--	--	--	--	101.4	425,703	--	--
4/75 - 5/75	35.2	147,689	--	--	43.4	182,343	7.82	32,851	5.09	25,519
Subtotal	1,143.9	4,663,140	21.56	90,527	232.0	974,824	463.0	1,916,218	14.36	64,466
Total	1,397.5 million gallons or 5,728,491 wet tons						477.4 million gallons or 1,980,684 wet tons			

times would have been 15.2 and 53.2 months, respectively. Because it is desirable to provide at least a 6-month storage or retention time, the ultimate acreage application of fields that should be developed can be estimated as follows:

$$\text{Maximum Acreage} = \frac{\text{Total Volume of Holding Basins}}{\text{Sludge Application per 6 Months}}$$

Based on a 20 dt/acre/year application rate and a 4% solids content, the ultimate acreage of application fields would be approximately 26,960.

Some substandard sludge is known to have been shipped to the project site. Subsequent environmental effects resulting from transporting substandard sludge cannot be assessed because sludge actually applied may have very different characteristics, depending on time in storage, mixing with supernatant, and so forth. However, any air pollution from sludge odors and aerosolization and contamination of surface water, groundwater and soil from sludge application would be complicated and abetted by continued shipment of subgrade sludge. As for the quality of applied sludge, it is important to bear in mind that any adverse environmental effects estimated from previous sludge applications may substantially understate their potential because the pollutant concentrations in sludge applied during the past developmental period have been atypically low. Also, average retention time in the holding basins has been much longer than planned.

A procedure must be implemented to ensure that only good quality sludge is shipped to Fulton County. Substandard sludge must be stored prior to shipment until its quality conforms with required standards. The capacity of the holding basins provides for a sufficiently long storage time, which should guarantee the destruction of pathogens in the sludge, but this does not alleviate the potential for odor problems, especially those associated with substandard sludge. Therefore, prolonged storage of sludge in the Lawndale lagoons prior to shipment to Fulton County is recommended as a mitigative measure.

B. THEORETICAL CONSIDERATIONS IN ODOR EMISSION

Odor is defined as the sensation of smell perceived as a result of olfactory stimulation by an odorant. Odorants range from inorganic gases and vapors to the full spectrum of organic compounds. Many malodorous substances, including mercaptans, hydrogen sulfides, sulfides, organic sulfur homologues, ammonia, decayed bacteria, and partially oxidized complex organics or amines have been identified in sludge from anaerobic digesters. These odorants are generated by microbiological activity in the sludge. Odor can be described by quality and intensity. The problems encountered in odor assessment for this study include:

- Mechanisms of odor generation
- Spectra of odorants from digested sludge
- Sources of odor emission
- Factors of odor emission strength such as sludge quality and extent of treatment
- Accuracy of odor identification and measurement.

Theoretical considerations in odor emission and detection are presented in this section to facilitate an understanding and subsequent assessment of the odor potential of sludge holding basins and of alternative sludge application methods at the project site.

1. Aerosolization and Volatilization

Emission of odor from liquid sludge occurs by aerosolization and volatilization. Volatilization or evaporation of chemical substances in water is influenced by air temperature and humidity, wind speed, and turbulence in the water body. The rate of evaporation depends upon the mass transfer rate of the chemical species in either the fluids or liquid phase. For low-solubility gases such as alkanes or mercury, the evaporation rate is liquid phase controlled; that is, the chemical species encounters more resistance in escaping from the liquid phase than from entering the gaseous phase. The evaporation rate of water soluble gases such as sulfur dioxide is vapor phase controlled.

Evaporation potential of a compound is indicated by half-life. Evaporative half-life is defined as the time required for evaporation to reduce the bulk concentration of a dissolved compound to half of its original concentration. The term is always accompanied by the depth of the water body because of possible stratification. Each stratum has a different mixing or turbulence regime. The solubility, vapor pressure, and half-life of some contaminants in a water body with a depth of one meter are given below in Table VII-5. The table shows that most of these compounds evaporate rapidly from solution.

Table VII-5. Solubility, Vapor Pressure and Evaporative Half-Life of Chemicals in Aqueous Solution at 25°C (Mackay and Leinonen, 1975)

Compound	Solubility (mg/l)	Vapor Pressure (mm Hg)	Half-Life (hrs, 1m depth)
n-Octane	0.66	14.1	5.55
Benzene	1,780	95.2	4.81
Toluene	515	28.4	5.18
o-Xylene	175	6.6	5.61
Biphenyl	7.48	0.057	7.52
DDT	1.2×10^{-3}	1×10^{-7}	73.9
Aldrin	0.2	6×10^{-6}	185
Mercury	3×10^{-2}	1.3×10^{-3}	7.53

When the water body is turbulent with rapid exchange of properties between the surface layer and the bulk, or during white-capping on a lake or ocean, the evaporation rate may increase. Low relative humidity and high temperature encourage evaporation, and vice versa. However, the influence of these factors on the evaporation of low-solubility chemicals is limited, because the mass transfer rates and aqueous solubilities of these substances are relatively insensitive to temperature. The effects of temperature on the vapor pressures of highly soluble substances, such as sulfur dioxide,can significantly influence the evaporation rate (Mackay and Leinonen, 1975). The effect of temperature on the evaporation of substances of intermediate solubility such as hydrogen sulfide, chlorine, or ammonia, is moderate (Fair, Geyer, and Morris, 1954).

When sewage sludge is stored in holding basins, volatilization may be the dominant mechanism for the release of odor-producing substances, unless white-capping occurs. White caps signify the presence of air bubbles collapsing at the water surface, generating minute airborne water droplets known as liquid aerosols. Evaporation from liquid aerosols can be significantly higher than evaporation from a plane water surface or a water body of equalized mass. This is because aerosolization increases the amount of surface area exposed to the atmosphere.

As aerosols decrease in size, vapor pressure increases at the droplet surface, further encouraging evaporation. However, evaporation increases the salt concentration of a liquid aerosol, decreasing vapor pressure and correspondingly decreasing evaporation rates (Squire, 1951). In addition, the ventilation effects around a liquid aerosol, as determined by terminal settling velocity, aerosol size, and internal circulation currents, can influence evaporation to a minor extent (Fletcher, 1962; Hanna, 1974).

2. Ammonia and Other Emission Sources

Odor emissions from sludge applied to soil may occur by mechanisms other than aerosolization and volatilization. For example, ammonia may undergo a series of physical, chemical, and biological reactions after sludge is sprayed on or incorporated into soil. Ammonia nitrogen may be adsorbed in the lattices of clay particles or remain freely soluble in the soil solution. The adsorbed ammonia may be fixed with clay molecules or held by cation exchange sites on clay particles, and is readily exchangeable with other anions in the soil. Water soluble ammonia also remains in the soil. The ammonia lost from the soil is either volatilized as gaseous ammonia or released as nitrogen gas by microbial nitrification and denitrification reactions. The extent of these reactions and the distribution of ammonia in the soil, liquid, or gaseous phases depends on:

- Sludge quality and quantity
- Season of sludge application
- Decomposition rate of sludge organic matter
- Fertility of the spoil material
- Soil moisture content
- Soil pH and clay mineralogy
- Availability of air in the soil
- Vegetative cover
- Rainfall and temperature
- Miscellaneous meteorological factors.

The MSDGC conducted a study of ammonia volatilization from a sludge-treated calcareous mine spoil. The study revealed that at 25^{o}C, more than 43% of the ammonia nitrogen added to the soil volatilizes into the atmosphere one week after sludge application. This value represented nearly the total amount of nitrogen that would be volatilized (MSDGC, 1974). This phenomenon is rather independent of the sludge application rate. The application rates tested in the study were zero, 10, 20, and 40 dry tons of sludge per acre of spoil land. Based on an ammonia nitrogen content of 1,540 milligrams per liter and a sludge application rate of 40 dry tons per acre, approximately 768 pounds per acre of ammonia nitrogen were volatilized, 398 pounds of ammonia nitrogen were fixed by clay minerals, and 282 pounds were in water soluble and exchangeable form available for plant nutrition (MSDGC, 1974). These figures ignore mineralization of organic nitrogen and immobilization of inorganic nitrogen by bacteria.

It must be noted that many chemicals or sludge constituents may be responsible for odor generation. These may undergo reactions similar to those for ammonia nitrogen or they may react differently. For example, hydrogen sulfide may be volatilized, oxidized to sulfate by chemical or biological reactions, precipitated by cations to form less soluble sulfide compounds, converted to other complex compounds, or assimilated by bacteria for biomass synthesis. The emission of a given malodorant is therefore the consequence of a complicated chemical and microbiological system for which no accurate method of quantification or model is as yet available.

The odor emission potential of sludge is determined, in part, by sludge characteristics, which, in turn, are partially determined by the type and extent of previous sludge treatment. As a general rule, fresh sludge produces more odor than digested sludge, and, odor associated with aerobically digested sludge is less of a problem than that with anaerobically digested sludge. Properly stabilized sludge should have a pH value higher than neutral, high alkalinity, and low levels of volatile solids and acids.

3. Identification and Measurement of Odor

Identification and measurement of industrial odors have been studied for several decades, but studies of odors from municipal wastewater and sludge are quite limited. The two types of odor measurements are source and ambient measurements. Generally, higher odor concentrations are encountered at the source than at a distance downwind. Source measurement procedures are therefore different from those for ambient measurement. However, the means of detecting or measuring odor in either instance are similar. Odor is detected and rated by the use of either human smell or mechanical instruments.

a. Sensory identification - The human nose is highly sensitive to many odors at extremely low concentrations, but is incapable of accurate, reproducible odor determinations. Human smell is affected by physiological factors such as age and health of the subject. Measurement techniques can be utilized to improve the reliability of sensory detection; the most common technique is the mixing or dilution method. An odor sample is diluted with pure air before being administered to a test panel of human subjects. Usually a series of diluted samples is prepared and given to the panel in descending order of dilution. Pure air is administered between each sample to sensitize the panel and to prevent olfactory fatigue. The odor threshold is defined as the concentration below which human smell cannot differentiate the sample from pure air. Table VII-6 presents the odor threshold and odor description for some chemicals.

The strength of an odor can conveniently be expressed in terms of its threshold value. There is the so-called odor unit, which is defined as the volumetric ratio of clean or odor-free air necessary to dilute an odor sample, so that 50% of the test panel cannot detect the odor (ASTM, D1391-57). For example, if an odor has strength of 1,000 odor units, it will take 1,000 cubic feet of pure air to dilute one cubic foot of the odorant so that 50% of the subjects will detect odor in the mixture. Odor samples can be taken by syringe, bag, or gas containers with the aid of sampling techniques used for air quality studies. The purity of odor substances, design of odor test facilities, methods of sampling and threshold determinations may all influence sensory detection of odor.

b. Chemical detection - More objective methods of odor evaluation have been attempted for years. These include wet chemistry, colorimetry, chromatography, and, recently, mass spectrometry. Wet chemical or colorimetric methods are chemical specific and suitable for single odorants and high odor concentrations. These methods have been used successfully for some odor-producing substances and sometimes correlate with the subjective findings of an odor test panel, but are far from satisfactory when multiple odorants coexist.

Table VII-6. Odor Thresholds and Descriptions (Leonardos, _et al_., 1969)

Chemical	Odor Threshold (ppm)	Odor Description
Acetaldehyde	0.21	Green sweet
Acetic acid	1.0	Sour
Acetone	100.0	Chemical sweet, pungent
Amine, dimethyl	0.047	Fishy
Amine, trimethyl	0.00021	Fishy, pungent
Ammonia	46.8	Pungent
Benzene	4.68	Solvent
Butyric acid	0.001	Sour
Carbon disulfide	0.21	Vegetable sulfide
Chlorine	0.314	Bleach, pungent
Diphenyl sulfide	0.0047	Burnt rubbery
Ethyl mercaptan	0.001	Earthy, sulfidy
Hydrogen sulfide gas	0.00047	Eggy sulfide
Methanol	100.0	Sweet
Methyl mercaptan	0.0021	Sulfidy, pungent
Nitrobenzene	0.0047	Shoe polish, pungent
Phenol	0.047	Medicinal
Pyridine	0.021	Burnt, pungent
Toluene (from coke)	4.68	Floral, pungent, solventy

Gas chromatography and mass spectrometry offer promising potential for odor identification and quantification because of their sensitivity to low chemical concentrations, reproducibility, and ability to verify and quantify multiple odorant mixtures. In applying these methods, a sample is drawn through a tube and odorants are "fixed" or "frozen" by coolants such as liquid nitrogen. The sample is brought to the laboratory and subjected to a programmed heating sequence. The release of chemicals from the sample are temperature dependent and thus follow the pre-programmed sequence. Separation of the chemicals is achieved by the successive release and passage of a given chemical through the gas chromatrograph or mass spectrometer, which identifies and quantifies the chemical. These two methods have the drawback of being unable to describe the composite quality of multi-odorants.

The accuracy and reproducibility of odor measurements rely also upon field conditions such as source characteristics and meteorological factors. Source strength is often neither constant in time nor uniform in space. The transient nature of an odor source makes the assessment of odor potential difficult, even though source strength can be determined accurately at a given moment and at a fixed receptor. Furthermore, the determination of long-term emission strength requires numerous short-term observations.

c. Ambient measurement - Upon leaving the source, physical and chemical atmospheric processes reduce the concentration of odorants by dilution, dispersion, and conversion. The dispersion of odorants is governed primarily by thermal and mechanical turbulence in the atmosphere, which are, in turn, determined by atmospheric stability, solar insolation or cloud cover, wind vectors, and other meterological parameters. Odor problems are primarily of local rather than regional concern. Therefore, topographical modification of regional meterological phenomena has a significant influence upon local transport and dispersion of odorants. Channelization of wind by local terrain and differential heating by land and water are the most significant topographical influences.

Receptors downwind from a constant-strength odor source will detect fluctuations in odor concentration resulting from wind shift and atmospheric turbulence. Consequently, short-term concentrations are always higher than long-term averages. For a period of more than 30 minutes, the downwind odor concentration usually forms a cross-wind profile which peaks directly downwind from the source, and decreases in both the downwind and cross-wind directions as a greater volume of clean air is available for dilution with increasing distance.

To predict the worst and the most probable concentrations and their occurring frequencies at a given location, daytime and nighttime observations are necessary. If seasonal variations are to be established, observations must be conducted over several seasons or years. Along with ambient measurements, source characteristics and meteorological parameters must be observed in order to correlate ambient odor levels with their influencing factors. However, for a rough terrain, the wind field is drastically modified by terrain features, and measurements taken at a hillside and at the bottom of a valley will differ because of wind chanelling, trapping, or lee wake effects. The location of a sampling station can therefore be crucial.

In view of the major requirements for successful odor measurement, problems and uncertainties can be anticipated. For example, daytime observations must not be applied to a nighttime situation, because daytime and nighttime emission characteristics and atmospheric conditions are quite different. For instance, radiational inversions occur more freuqently at night. Also, short-term observations cannot form the basis for long-term projections.

Because the synergistic and antagonistic phenomena of many coexisting odorants are not understood, measurement of individual odorants cannot be integrated to render a composite assessment that will correlate with human response. Because of limitations on instrument accuracy and measurement reproducibility, and because of constraints of time, resources and field conditions, odor assessments are generally non-quantitative.

C. ODOR POTENTIAL OF SLUDGE HOLDING BASINS

Odor monitoring conducted at the project site includes odor verification by the Midwest Research Institute and atmospheric ammonia monitoring at the holding basins by the MSDGC. These monitoring programs are discussed in the following section, along with an estimate of the atmospheric dilution capacity around the sludge holding basins. Potential odor impacts and measures to mitigate adverse effects of odor dispersion are presented at the conclusion.

1. Odor Complaint Data

The odor verification program undertaken by the Midwest Research Institute (MRI) under contract with the Fulton County Health Department was designed to pinpoint the source of an odor after a citizen complaint arose. Health Department personnel sent air samples from the complaint site to MRI for analysis by gas chromatography. This technique produces a chart containing a series of peaks, each peak corresponding to an individual chemical compound in the sample. The chart of the sample from the complaint site was compared with those of samples collected at possible odor sources in the project area. These sources included the MSDGC sludge holding basins, the sludge spraying operation on MSDGC property, the Canton sewage treatment plant, a cattle feedlot, and the gob piles and septic tanks common to the area.

The chromatographic analysis neither quantified odor intensity nor identified the chemical components of the samples. A series of "finger print" matchings was proposed to identify the responsible odor source. This approach was proven to be unsatisfactory in correlating odor complaints with any of the individual odor sources sampled. From the matching analysis of eight odor complaints, it was concluded that the probability of the odor originating from MSDGC sources was 0.71.

Figure VII-10 delineates the odor complaint sites and the wind direction and velocity at the time the complaints were made. The sites of the complaints indicate that the odors originated from the vicinity of the MSDGC property.

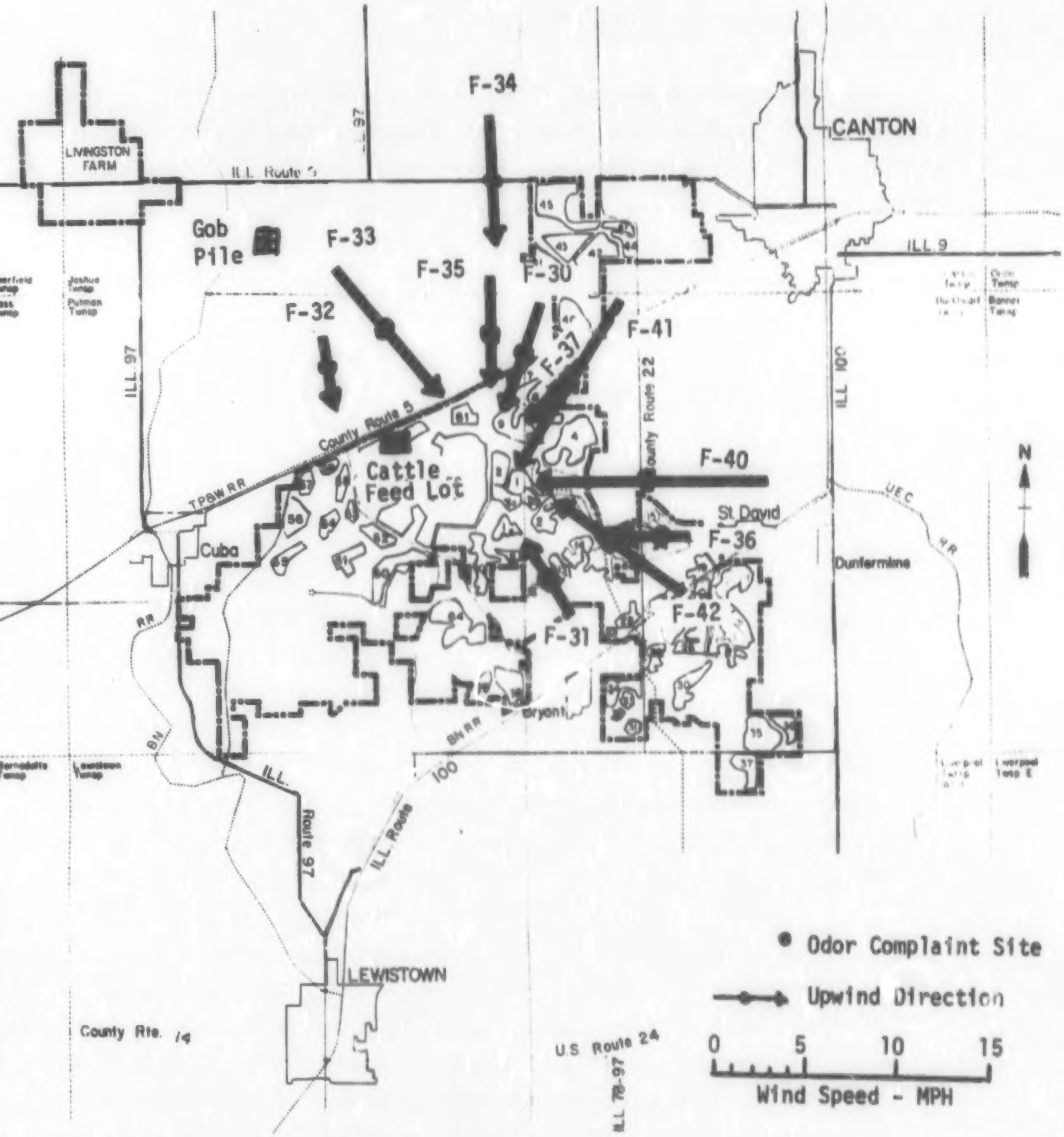

F-34
CANTON
LIVINGSTON FARM
ILL. Route 5
Gob Pile
F-33
F-35
F-30
F-32
F-41
F-37
ILL. 9
Deerfield Twnsp
Joshua Twnsp
Cass Twnsp
Putman Twnsp
ILL. 97
County Route 5
Cattle Feed Lot
ILL. 100
County Route 22
F-40
N
St. David
F-36
Dunfermline
TP&W RR
Cuba
F-42
F-31
Bryant
BN RR
BN
RR
UEC RR
Bernadotte Twnsp
Lewistown Twnsp
Liverpool Twnsp E
ILL. Route 97
ILL. Route 100
LEWISTOWN
County Rte. 14
U.S. Route 24
ILL 78-97
Odor Complaint Site
Upwind Direction
0
5
10
15
Wind Speed - MPH

Figure VII-10. Location of Odor Complaints, Wind Direction and Wind Velocity (Midwest Research Institute, 1974)

2. Atmospheric Ammonia Data

MSDGC personnel have been measuring atmospheric ammonia concentrations near the sludge holding basins since August 1973 (MSDGC, 1972a through 1975g). Samples are collected at the berm on the downwind side of the basins. Surface wind speed and direction, air temperature, and dew point are noted during the sampling period. The corresponding relative humidity can be calculated from the measured air temperature and dew point. (A sample data sheet is shown in Table III-5, page III-29.)

The ammonia study alone cannot satisfactorily disclose the magnitude of odor problems. This is supported by the fact that an earthy smell rather than a pungent ammonia odor was noticed during a field trip within the project property. Other odorants could therefore be present. The study of atmospheric ammonia does, however, help to understand the mechanisms of odor generation and odor impacts.

a. Influence of air temperature and humidity - As previously discussed, chemicals are liberated from a liquid solution by volatilization and aerosolization. The volatilization rate of ammonia depends on the aqueous ammonia concentration in the bulk water body, its atmospheric vapor pressure, and ambient temperature. Stratification occurring as a result of solid-liquid separation is expected to be very stable to 5 meters below the water surface of the holding basins (shown in Figure III-4, page III-6). The exchange of chemicals and heat between the bottom sediments and the supernatant are expected to be insignificant. Therefore, the volatilization rate in the liquid phase depends primarily on the ammonia concentration in the supernatant, which remains quite constant.

To examine the influence of ambient air temperature on ammonia liberation from the sludge holding basins, atmospheric ammonia concentrations are plotted against air temperature in Figure VII-11. Disregarding wind speed and atmospheric humidity, which may affect

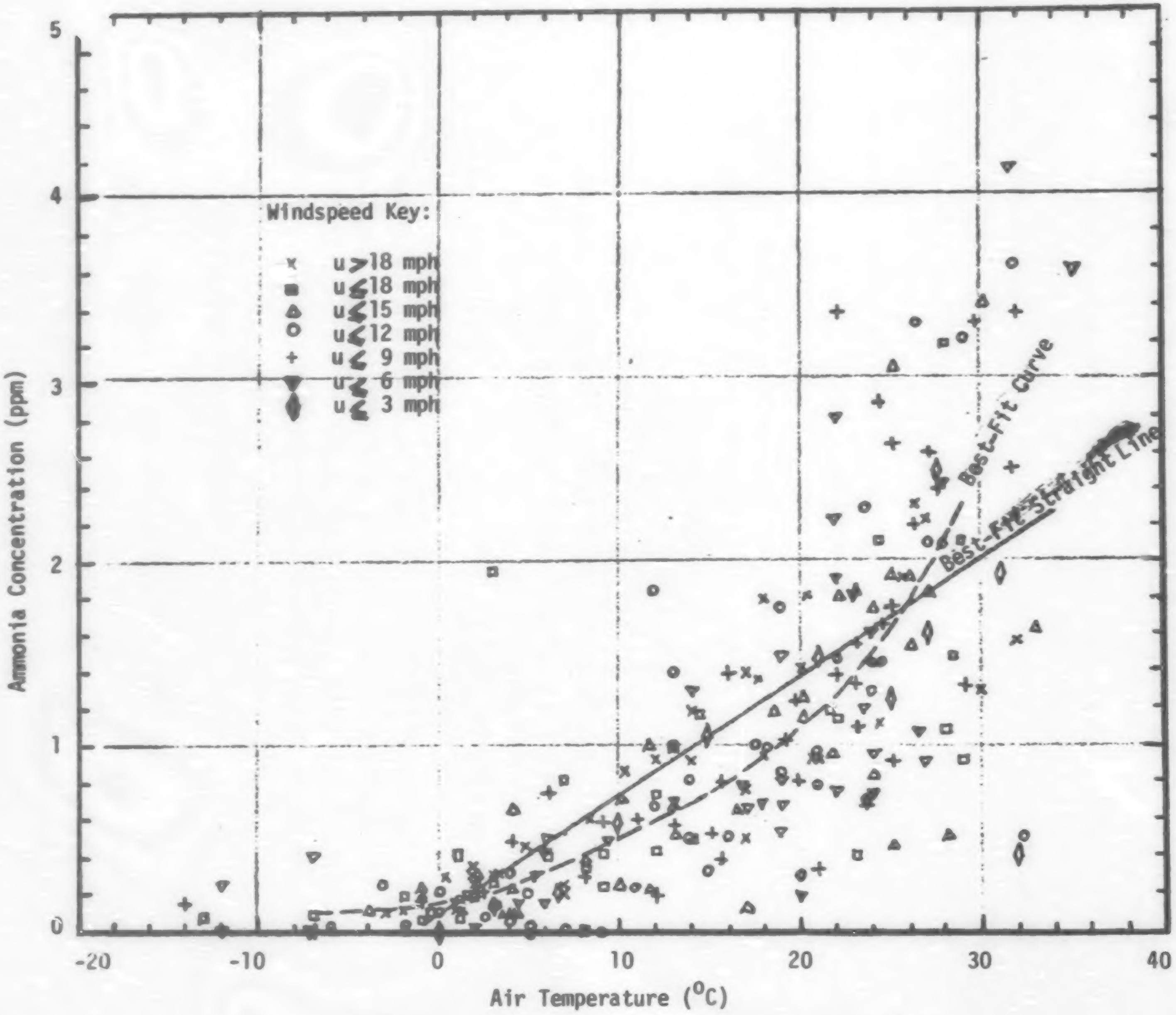


Figure VII -11. Correlation of Atmospheric Ammonia Concentration with Ambient Air Temperature (MSDGC, 1972a through 1975g; Enviro Control, Inc., 1976)

the volatilization rate, atmospheric ammonia concentration correlates well with ambient air temperature. Using the least square method with 235 observations, the best-fit straight line correlation yields a slope of 0.06 ppm per degree (^{o}C), meaning that a $10^{o}C$ temperature increase causes an increase of 0.6 ppm in source ammonia concentration at the sludge holding basins. A logarithmic correlation may generalize this positive correlation more satisfactorily without risking negative ammonia values in low temperature ranges. The logarithmic correlation may be approximated by the dashed curve in Figure VII-11 (page VII-26).

Apparently the vertical spreading of data points for a given air temperature in Figure VII-11 results, at least partially, from humidity variation. Disregarding the wind effects on atmospheric ammonia, the relationship between atmospheric ammonia and air temperature for an increment of relative humidity was analyzed. The relative humidity intervals used for analysis are 60-70, 71-80, 84-90, and 90-100%. The slope of correlation ranges from 0.066 to 0.088 ppm/^{o}C with the steepest slope associated with the lowest humidity and vice versa, as expected. This confirms that low relative humidity encourages evaporation or volatilization of ammonia for a given temperature increment.

b. Influence of wind speed and direction - To demonstrate the effect of wind on ammonia volatilization and aerosolization, atmospheric ammonia concentration was plotted against air temperature for seven wind speed intervals: 0-3, 3.1-6, 6.1-9.0, 9.1-12.0, 12.1-15.0, 15.1-18.0, and greater than 18.0 mph (these are shown separately in Appendix B). The number of observations ranges from 19 to 42. The slopes of correlation range from 0.045 to 0.069 ppm/^{o}C. The highest wind speed interval has a correlation slope of 0.057 ppm/^{o}C, which falls in the middle of the range of variation.

At a given temperature, the concentration of ammonia is approximately equal for all seven wind intervals. Because storm winds cause high horizontal advection or dispersion capacity, sludge in the holding basins must possess a high ammonia emission strength during windy periods in order to maintain a constant level of atmospheric ammonia over the basin surface. Because the effects of temperature on ammonia volatilization are limited, increased emission strength is probably due to wind turbulence causing white-capping and aerosolization of sludge. A theoretical estimation using Turner's diffusion model reveals a linear relationship between emission strength increase and the increase in wind speed (Turner, 1970). For example, when wind speed is increased from 10 mph to 15 mph, the emission strength is increased by 50%.

The frequency of wind of a given speed and direction is governed by regional meteorological events and topographical features. This phenomenon is depicted in the "wind rose" in Figure IV-4 (page IV-9). This directional wind frequency distribution results in a directional distribution of atmospheric ammonia. The percent occurrence of a range of ammonia concentrations in different directions is presented in Figure VII-12 and is referred to as an "ammonia rose".

Ammonia concentrations are broken into five intervals: 0-0.5, 0.51-1.0, 1.01-1.50, 1.51-2.0, and greater than 2.00 ppm. Eight directions or sectors are represented by bars. The probability of a given ammonia concentration occurring in a given sector is proportional to the length of its representative segment. The innermost segment represents the lowest ammonia concentration interval. As shown in the "ammonia rose", the southwesterly and southerly directions are associated with the low frequencies of ammonia concentration. The northerly directions are associated with the highest frequencies of high ammonia concentrations.

c. Frequencies of source concentrations - The source concentration of ammonia is quite variable and is multiple-parameter dependent. Among these parameters, air temperature and wind speed have

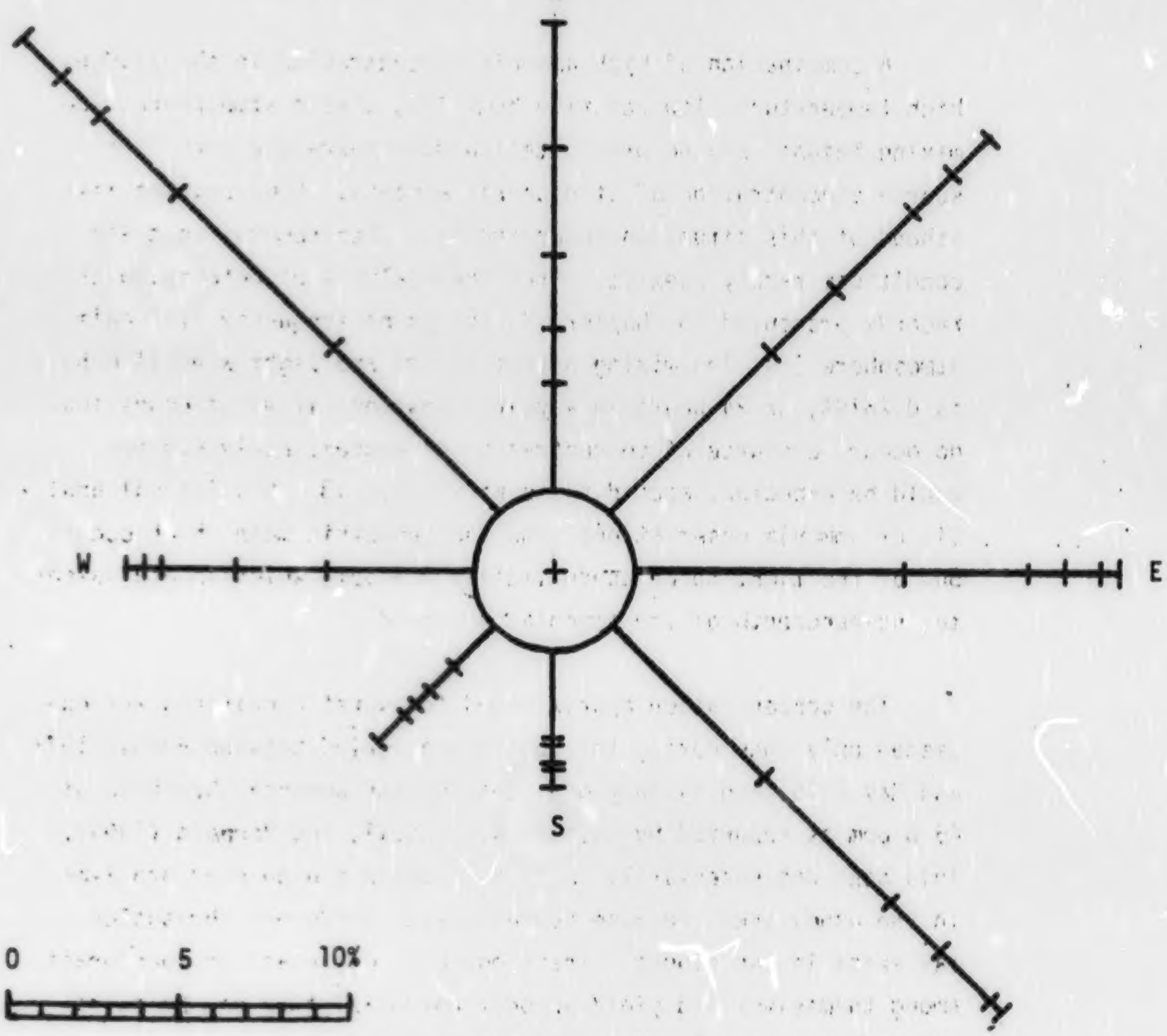


Figure VII-12. "Ammonia Rose"; Directional Annual Percent Frequency of Ammonia Concentration at the Project Site in the Ranges of 0-0.5, 0.51-1.0, 1.01-1.50, 1.51-2.0, and 2.01 ppm or Higher (MSDGC, 1972a through 1975g).

the most pronounced influence. Disregarding wind direction, the frequencies of ammonia concentrations less than or equal to a designated value are presented in Figure VII-13.

A combination of high ammonia concentration in the sludge, high temperature, low relative humidity, stable atmosphere, low mixing height, and no precipitation may generate a very high source concentration of atmospheric ammonia. However, the likelihood of this situation occurring is rather remote, as these conditions rarely coexist. From the analysis of meteorological records presented in Chapter IV, the joint frequency of a calm atmosphere (F), low mixing height (100m) and light wind (1 mph) is 0.2678%, or 24 hours in a year. However, if worst conditions do occur, a source of concentration of approximately 4.8 ppm would be expected, according to Figure VII-13. Statistical analysis of ammonia observations show the geometric mean which occurs 50% of the time, to be approximately 0.5 ppm, which is equivalent to one-hundredth of the ammonia threshold.

The concentration approximated for worst conditions was exceeded only once during the monitoring period between August 1973 and May 1975, and is only one-tenth of the ammonia threshold of 46.8 ppm as reported by Leonardos, Kendell, and Barnard (1969). This does not necessarily imply that there are no odor problems in the study area, because odorants with different thresholds may exist in the sludge. These odorants may react or counteract among themselves and yield an odor potential that can be extrapolated theoretically from the ammonia study.

d. Dilution and dispersion of source concentrations - Turner's diffusion model for an area source was employed to estimate the atmospheric dilution capacity around the study area (Turner, 1970). Assuming the source concentration to be at unity at the geometrical center of the holding basins, the ground-level ammonia concentrations directly downwind from the source are determined for

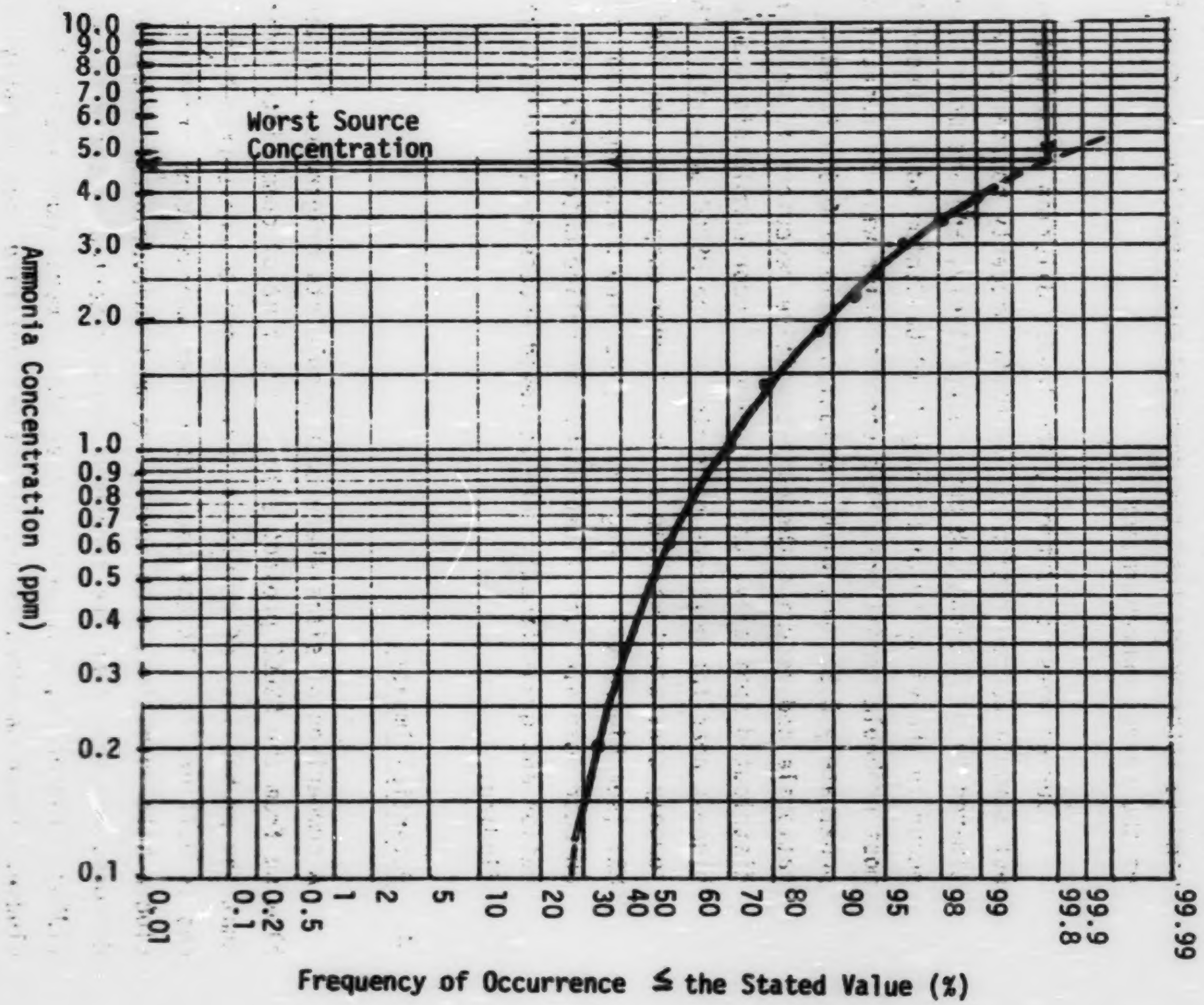


Figure VII-13. Frequencies of Source Concentrations of Atmospheric Ammonia (NH_3), (MSDGC, 1972a through 1975g; Enviro Control, Inc., 1976)

both the worst and the most probable conditions (see Section IV.A). Their isopleths or contours of equal concentration are shown separately in Figures VII-14 and VII-15. The dilution capacity of the atmosphere is expressed as a ratio, because the source concentration is normalized to unity. A dilution ratio of 0.7 at a downwind receptor means that the downwind concentration is seven-tenths of the source concentration.

During worst conditions, the lowest dilution ratio and highest ammonia concentration at the MSDGC property boundaries are estimated to be 0.8 and 3.8 ppm, respectively, and are most likely to occur in the vicinity of Highway 5 (Cuba-Canton Rd.). Under the most probable conditions, this concentration will be reduced to approximately 0.25 ppm, with a dilution ratio of 0.5. Based on this rationale and assuming the odor-sensitive receptors to be uniformly distributed spatially, the incidence of odor complaints should be highest near the northern perimeter of the MSDGC property. This is roughly consistent with locations of odor complaints verified by MRI (see Figure VII-1, page VII-3). Continued and improved efforts on odor complaint verification by controlled detection, identification and quantification are believed necessary to confirm this finding.

3. Potential Impacts

A comparison of sites where odor complaints originate with winds blowing from the MSDGC project site at the time of complaints indicates that the probability of complaints arising due to odors from MSDGC sources is 0.71 or 71%. It has been shown that ammonia concentrations at the sludge holding basins, even during the most unfavorable meterological conditions, are less than the threshold value reported by Leonardos et al. (1969). Therefore, malodorants other than ammonia must reside in the sludge. These malodorants are as yet unidentified, but probably act synergistically to generate an earthy smell from the sludge.

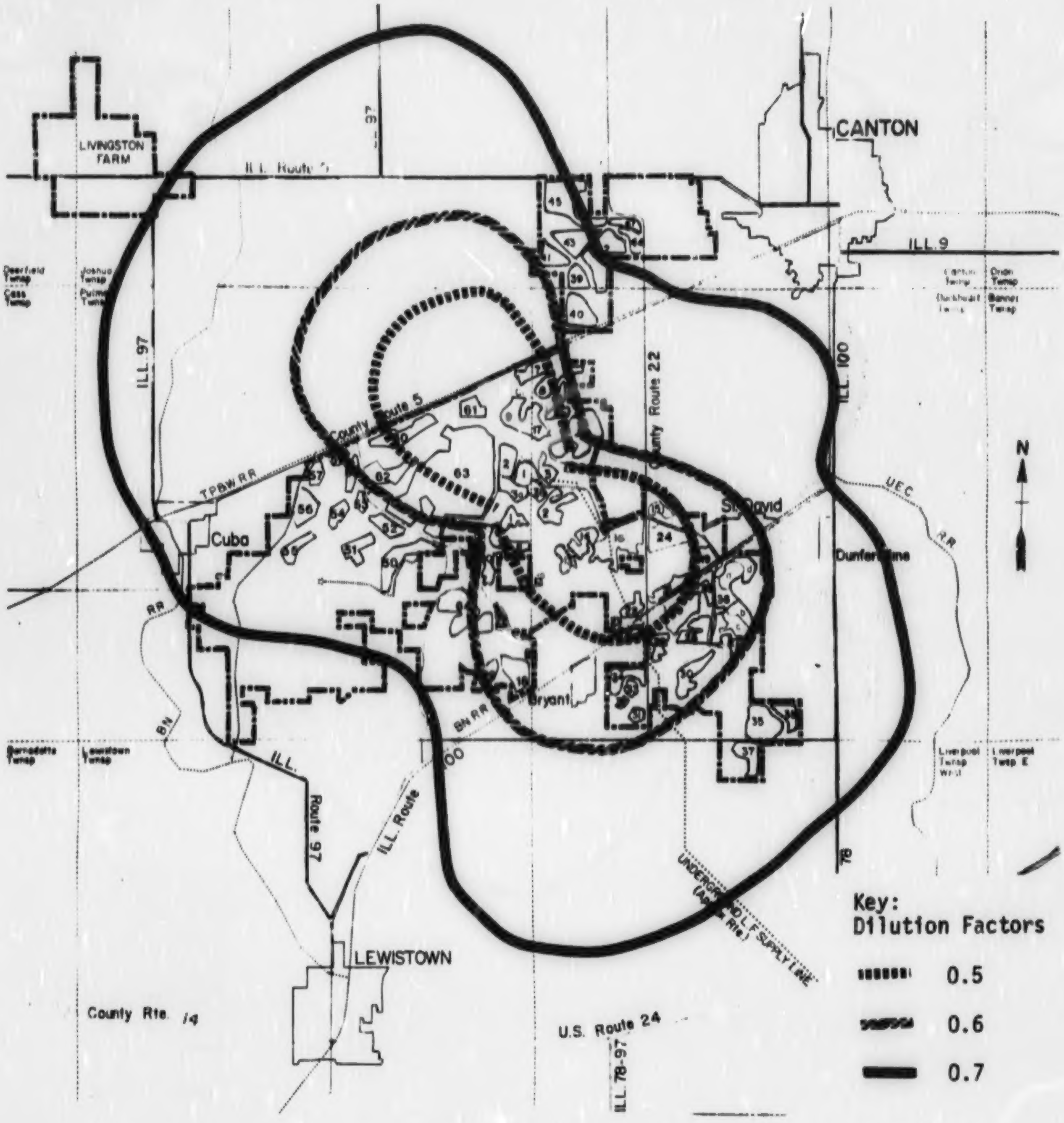

LIVINGSTON FARM
ILL. Route 5
97
CANTON
ILL. 9
Deerfield Twnsp
Joshua Twnsp
Cass Twnsp
Putman Twnsp
Canton Twnsp
Orion Twnsp
Buckheart Twnsp
Banner Twnsp
ILL. 97
County Route 5
County Route 22
ILL. 100
TP&W RR
Cuba
St. David
Dunfermline
UEC RR
N
RR
Bryant
BN RR
BN
Bernadotte Twnsp
Lewistown Twnsp
Liverpool Twnsp West
Liverpool Twsp E
ILL. Route 97
ILL. Route 100
78
UNDERGROUND L.F. SUPPLY LINE (Along Rte)
LEWISTOWN
County Rte. 14
U.S. Route 24
ILL. 78-97
45
43
39
40
61
63
62
57
56
55
54
53
52
51
50
24
16
35
37
Key:
Dilution Factors
0.5
0.6
0.7

Figure VII-14. Downwind Atmospheric Dilution Ratio Under the Worst Conditions (Enviro Control, Inc., 1975).

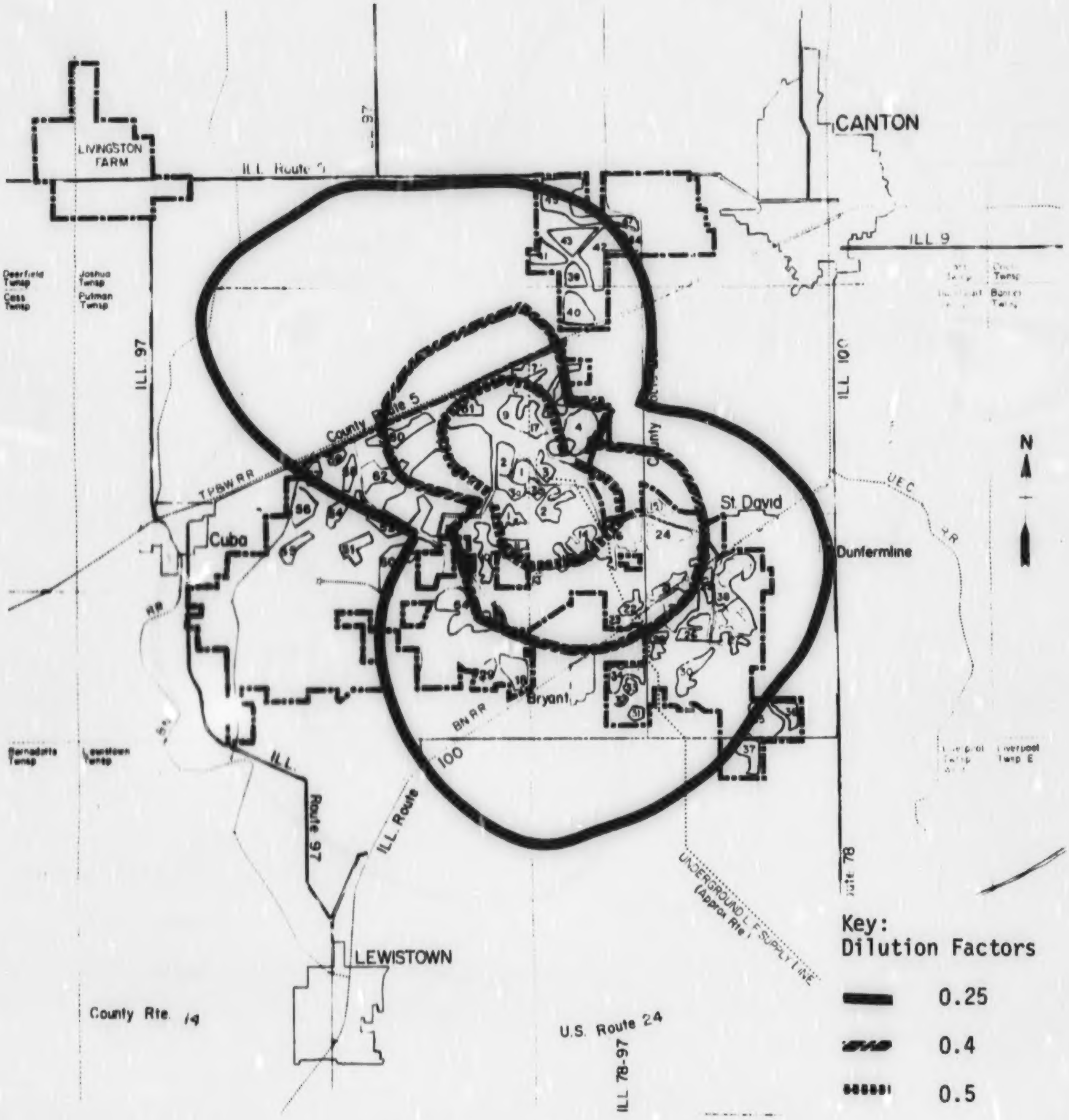

LIVINGSTON FARM
ILL. Route 5
97
CANTON
ILL 9
Deerfield Twnsp
Joshua Twnsp
Cass Twnsp
Putman Twnsp
ILL 97
ILL 100
County Route 5
T P & W R R
Cuba
St. David
Dunfermline
U E C R R
N
Bryant
BN R R
100
Bernadotte Twnsp
Lewistown Twnsp
Liverpool Twnsp E
ILL. Route 97
ILL. Route
LEWISTOWN
UNDERGROUND L.F. SUPPLY LINE (Approx Rte.)
Route 78
County Rte. 74
U.S. Route 24
ILL 78-97
Key:
Dilution Factors
0.25
0.4
0.5

Figure VII-15. Downwind Atmospheric Dilution Ratio Under the Most Probable Conditions (Enviro Control, Inc., 1975)

Atmospheric dilution in the project area is estimated to reduce ammonia and other odorant concentrations 4 miles downwind by approximately two to four times under worst and most probable conditions, respectively. This odorant dilution is considered ineffective in the abatement of odor problems. If the emission strength of odorants at the holding basins remains the same, odor complaints will probably continue to be raised.

The odor impact area apparently is contained by a circle with a radius of approximately 4 to 5 miles. This circle includes the communities of St. David, Bryant, Cuba, and the outskirts of southwest Canton. Considering the prevailing winds and dispersion pattern of airborne odorants, farm households along the northerly perimeter of the MSDGC property will experience most of the odor impact. Infrequent periods of severe impact could result from subsidence inversion which produces atmospheric stagnation and high air temperatures.

4. Mitigation of Adverse Effects

Atmospheric dispersion is estimated to be inadequate for proper odor dilution. Providing an increased buffer distance between the sludge holding basins and sensitive receptors is, therefore, an ineffective mitigative measure. Mitigative measures should aim at reducing emission strength at the source. Three alternatives for this type of mitigation are discussed below.

Improving sludge quality would reduce malodorant concentrations, and would thereby reduce odor potential. Sludge quality can be improved by increasing the storage time of properly digested sludge in the Chicago Lawndale lagoons.

White-capping at the surface of the holding basins due to wind promotes sludge aerosolization, which is one major mechanism for odor generation. The use of wind barriers such as tall, dense hedgerows or fences around the holding basin berms, or floating baffles within the basins, could reduce surface turbulence and wave action which intensify odor emissions. The present requirement of a 4-foot freeboard from the sludge surface to the top of the berm provides wind baffling only for a short distance downwind.

Odor emission from the sludge holding basins correlates with ambient air temperature, which helps to control the evaporation rate of sludge. Chemical suppression of sludge evaporation, using a low-volatility liquid film which increases surface tension, might be effective in reducing odor potential during periods of high air temperature. The economic and technical feasibility of this option require further investigation.

Odor masking or counteracting agents have been used successfully for industrial odor abatement. The MSDGC has spread Odoban 518-D, manufactured by Rhodia, Inc., around the berms of the sludge holding basins. Monitoring the effectiveness of this and other odor masking agents is necessary. If this proves to be an effective odor control method without adverse environmental side effects, it could be applied during periods of unfavorable weather conditions when odor propagation is greatest. Continuous monitoring for odor detection and periodic identification of odorant species are important in judging the effectiveness of control measures.

The extreme remedy of constructing deeper holding basins having less exposed surface area in order to reduce evaporation is probably infeasible both economically and technically. Problems in lining the basins and mixing solids with supernatant could prove overwhelming. Also, an increased basin freeboard would prove infeasible; increased wind sheltering would be slight in exchange for a great reduction in storage capacity.

D. ODOR POTENTIAL OF ALTERNATIVE SLUDGE APPLICATION METHODS

A number of methods are available for applying liquid sludge to soil. Five alternative methods of sludge application are described in this section along with their mechanisms and potential for producing odors. The five methods discussed are:

- Pressurized spraying
- Overland flow
- Infiltration-percolation by shallow impoundment
- Soil incorporation
- Soil injection.

Overland flow and infiltration-percolation by shallow impoundment can be categorized as surface spreading methods. Soil incorporation and soil injection can be categorized as surface penetration methods.

1. Pressurized Pivotal Spraying

In this method, sludge is sprayed onto the field through a pressurized nozzle. The nozzle opening is normally at least 2-inches in diameter to prevent clogging. The nozzle pressure used in the project is 90 psi and the spray rate is 600 gpm. This yields a horizontal throw of approximately 120 to 150 feet when the nozzle is inclined at an angle of 45°.

Odor is generated in this method by sludge aerosolization and subsequent volatilization of malodorants. The volatilization of malodorants from soil surfaces moistened by sludge and localized ponding of sludge also increase odor generation. Ammonia volatilization from a sludge surface or field applied with sludge is discussed in Sections A and B of this chapter. Only the aerosolization and subsequent volatilization are discussed here, but the same theoretical considerations can be applied to other application methods.

a. Formation and evaporation of aerosols - After being ejected from the sprayer nozzle, liquid sludge breaks up into blobs or droplets. Large blobs fall rapidly to the ground with little volatilization or evaporation during travel. Small sludge droplets or aerosols have a slow terminal settling velocity, resulting from the balance between gravity and drag resistance of the air, and may remain airborne for a long time. While residing in the air, the aerosols volatilize at a rate depending on aerosol size and ambient conditions such as atmospheric stability, wind speed, humidity, and temperature.

The quantity and size of sludge aerosols generated by the sprayer gun are governed by the operating pressure and the shape of the nozzle opening. As the energy applied to a unit mass of sludge increases, the proportion of aerosols increases while the mean size decreases (Fuchs, 1964). The aerosols are polydispersed rather than uniform in size. The size spectrum of aerosols generated by this type of irrigation sprayer is unavailable in the literature. It is therefore necessary to examine the evaporation potential as a function of aerosol size.

A meaningful indication of the evaporation rate of a liquid aerosol is the mass half-life. The mass half-life of a droplet is the time required for the droplet to evaporate or volatilize to one half of its original mass. Figure VII-15 records the mass half-lives of aerosols of different sizes containing a sodium chloride concentration of 8,000 mg/l, where the atmosphere is still, the temperature is 10°C, and the humidity varies. The mass half-life ranges from .001 to approximately 100 seconds for aerosol sizes between 1 and 500 microns and a relative humidity ranging between 40 and 90 percent. For a given aerosol size, the mass half-life increases with increasing relative humidity. High relative humidity therefore hinders evaporation of water and malodorants from sludge aerosols. Using the same thermal dynamic equation, which establishes the relationship between aerosol evaporation rate and the ambient relative humidity, temperature, and salt or impurity content, one can demonstrate that aerosol evaporation rates increase with increasing temperatures and decreasing salt or impurity concentrations (Squires, 1951; Fletcher, 1962; Hanna, 1974).

While airborne, small liquid aerosols may evaporate completely and leave dried salt nuclei in the atmosphere; large aerosols may not evaporate completely before striking the ground. The degree of evaporation of a liquid aerosol is thus governed by its atmospheric residence time, or the time during which the aerosol remains airborne. The residence time of a liquid aerosol emitted by a sprayer gun at a given height and angle of inclination, in still air, is plotted in Figure VII-16. This graph shows that residence time decreases with increasing aerosol size, lower emission height, and less inclination of the sprayer gun. For the construction of these residence time curves, it has been assumed that the operating pressure at the nozzle is proportionately reduced so that the horizontal velocity of the jet is the same for various combinations of nozzle height and inclination.

Figure VII-16 shows that the residence time of a liquid aerosol can be reduced tenfold when the nozzle or emission height is reduced from 40 ft. to 5 ft. and the inclination reduced from 45° to 0°. Evaporation from aerosols larger than approximately 50 microns will therefore decrease significantly, because their residence times are small compared to their mass half-lives. The reduction in evaporation from aerosols in the micron and sub-micron spectra by lowering emission height and the angle of inclination is of little significance. However, as the operating pressure is reduced with a lower emission height and inclination, the energy applied to a unit mass of sludge is reduced so that the production of aerosols, especially of fine aerosols, is reduced.

b. Emission strength of aerosols - An estimation of the ammonia emission strength from spraying is necessary to compare its odor potential with that from the sludge holding basins. This comparison

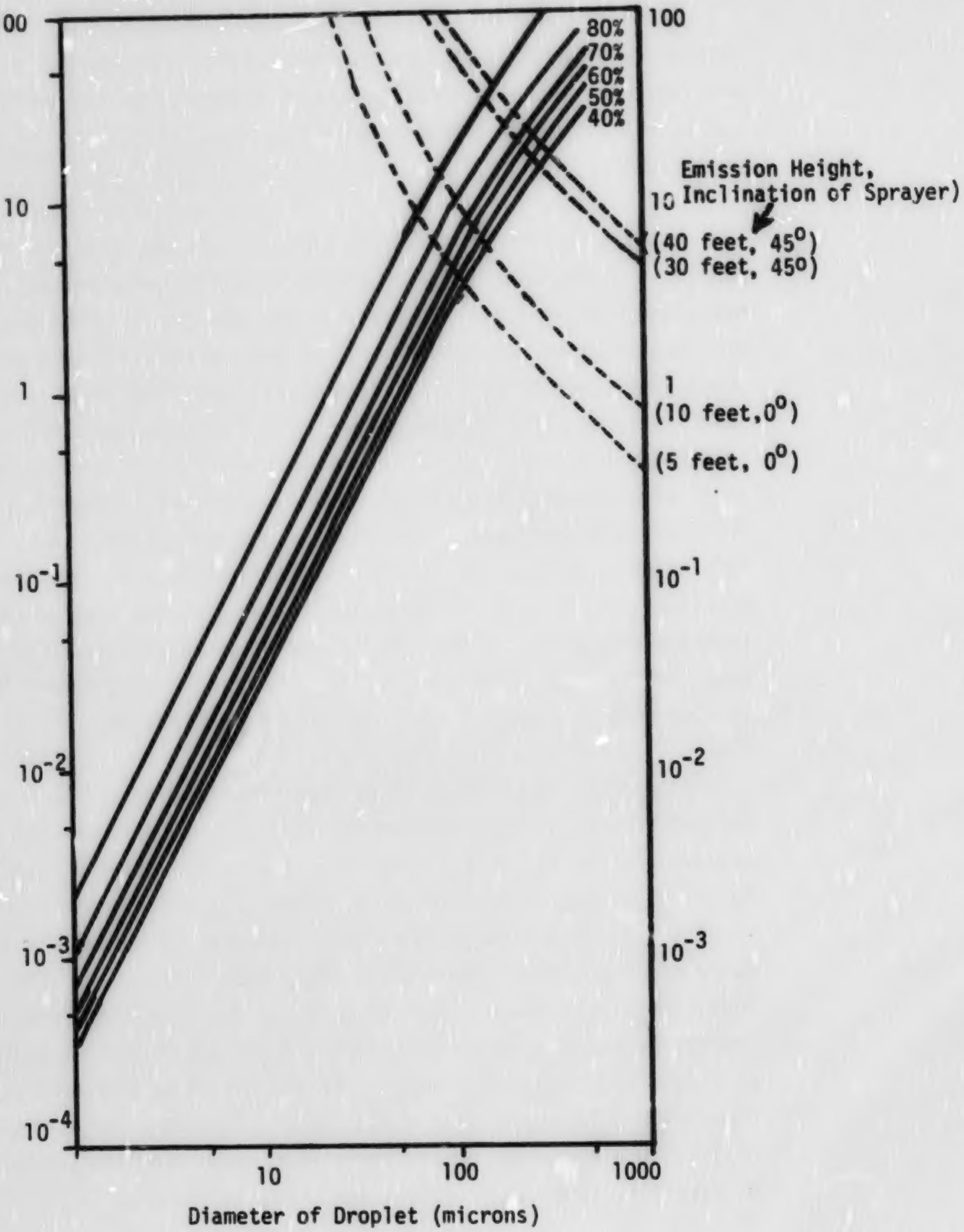


Figure VII-16. Mass Half-Life and Residence Time of Aerosols (Containing 8,000 mg/l of NaCl and moving at terminal velocity with an ambient temperature of 10°C); (Squires, 1951; Fletcher, 1962; Hanna, 1974; Enviro Control, Inc., 1976)

is based on the following assumptions:

- 0.3% of the liquid sludge is transformed into aerosols with a mass mean diameter of either 50 or 120 microns, mean mass half-life of 9 seconds, and equal mean residence times
- Relative humidity is 75%
- Salt and impurity content of sludge is equivalent to 8,000 mg/l of sodium chloride.
- Emission height is 10 ft.
- Ammonia concentration is 1,500 mg/l in the liquid sludge.

The emission strength of the spray, in terms of atmospheric ammonia, is approximately 1.1×10^{-4} cubic meters of ammonia per second for each sprayer with a mean diameter of 120 microns. If the mean diameter of the sludge aerosols is 50 microns, the ammonia emission rate is approximately doubled to 2.3×10^{-4} m^3/sec Each sprayer covers an area ranging from 120 to 150 feet in radius (or approximately 1 acre); these two aerosol sizes result in rates of 1.1×10^{-4} m^3/sec and 2.3×10^{-4} m^3/sec of ammonia per acre, respectively. The emission strength will be increased if a higher proportion of sludge is aerosolized, and vice versa.

Most of the sludge from the sprayer will reach the ground. Part of the sludge reaching the soil will be volatilized. According to MSDGC's study of ammonia volatilization from sludge-treated spoils, about 43% of the ammonia added to the spoil is volatilized within the first week (MSDGC, 1974m). With a sludge spraying rate of 40 dry tons per acre per day, which is extraordinarily high, the average emission rate of ammonia at 25°C is roughly 7.6×10^{-4} m^3/sec/acre in the first week. If the sludge is applied in six runs with a week of separation between each run, the emission rate is estimated conservatively to be 1.3×10^{-4} m^3/sec/acre. Assuming a 600 gpm nozzle flow, the allotted amount of sludge can be applied to an acre in 3 hours. If the application rate is reduced, the ammonia emission rate or odor potential is correspondingly reduced.

The foregoing estimation reveals that the odor emission strength from sludge aerosols is in the same order of magnitude as that from the evaporation of sludge from treated spoils. However, the total aerosol volume is only a fraction of 1% of the sludge volume applied to the field. Obviously, the odor emission potential of aerosols generated by the sprayer is approximately 50 to 100 times that of the sludge in the spoils.

The great increase in odor emission by sludge aerosolization is attributable to the great expansion of exposed surface area. The surface area of exposure is the area of air-liquid interface on which volatilization or evaporation occurs. Assuming that it takes three sprayer runs to apply 40 dry tons of sludge per acre, the total exposed surface area without aerosolization will be 12,000 square meters. If 0.3% of the sprayed sludge is aerosolized to a mass mean diameter of 120 microns, the surface area will be approximately 140,000 square meters, which is equivalent to a twelvefold increase. If the mean aerosol size is 50 microns instead of 120 microns, the total exposed surface area will be increased to 340,000 square meters.

2. Surface Spreading

Surface spreading of sludge includes overland flow and infiltration-percolation. With overland flow, sludge is applied to the land in a sheet flow or in ploughed furrows from distributors which may be ditches or gated pipes with side outlets (see Figure VII-17). Liquid sludge percolates through soil and at the same time evaporates into the atmosphere. Sludge collected at downhill runoff collection ditches can be pumped back to the ridge distributors or released to retention basins. The exposed surface area of sludge is limited to the land surface, because sludge aerosolization does not occur. Therefore, the potential for odor emission in this method is far less than that for spraying. The exposed surface area of sludge is least if a ridge-and-furrow surface is employed.

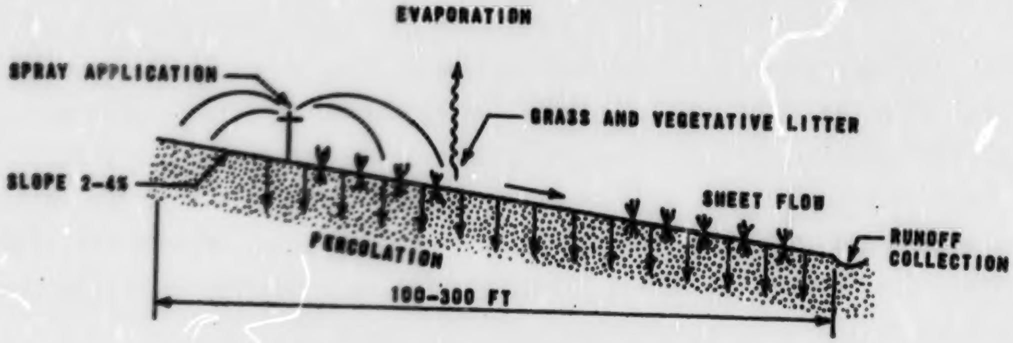

EVAPORATION
SPRAY APPLICATION
GRASS AND VEGETATIVE LITTER
SLOPE 2-4%
SHEET FLOW
RUNOFF COLLECTION
PERCOLATION
100-300 FT

Figure VII-17. Overland Flow Application of Sludge (U.S. EPA, 1975; Enviro Control, Inc., 1976)

Infiltration-percolation of sludge is shown below in Figure VII-18. Sludge is diverted to shallow ditches or impoundments which encourage infiltration and percolation through the soil. Evaporation and odor potential are less than with overland flow application because of reduced exposed surface area. Infiltration-percolation can result in a recharge mound if the horizontal movement of groundwater is exceeded by vertical percolation. Of all sludge application methods, the potential for groundwater contamination is highest in this process. Because the sludge is confined to a system of ditches, ponds or terrace impoundments, only limited types of crops can be grown.

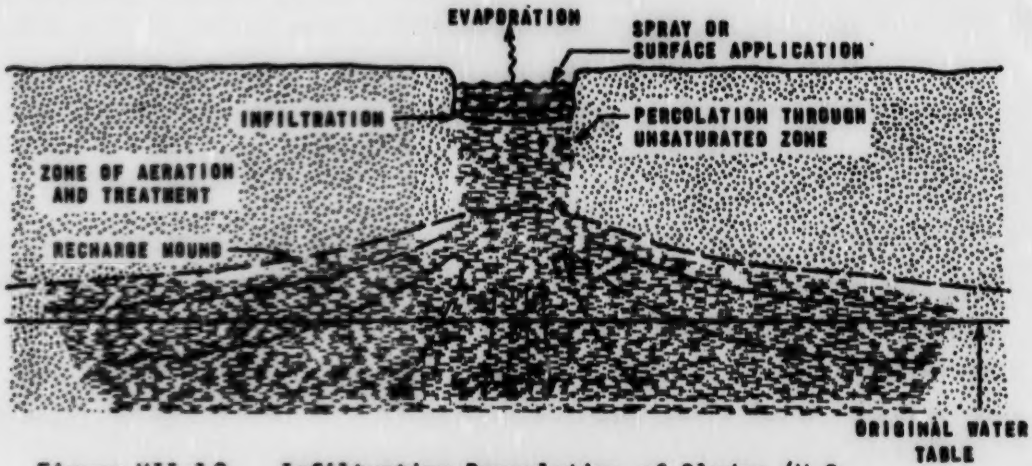

EVAPORATION
SPRAY OR SURFACE APPLICATION
INFILTRATION
PERCOLATION THROUGH UNSATURATED ZONE
ZONE OF AERATION AND TREATMENT
RECHARGE MOUND
ORIGINAL WATER TABLE

Figure VII-18. Infiltration-Percolation of Sludge (U.S. EPA, 1975; Enviro Control, Inc., 1976)

3. Surface Penetration

Surface penetration methods include soil incorporation and soil injection (see Chapter III). Soil incorporation is accomplished by tilling machines and incorporates sludge to almost the entire soil cross-section. In the soil injection method, sludge is injected into slots formed in the soil by a tool shank. (These two methods are illustrated in Figures III- 6 and III-8, pages III-10 and III-13, respectively.)

Neither of these methods generate sludge aerosols. Odor emission is a result of the evaporation or volatilization of malodorants from the sludge-incorporated soils. The exposed surface area is much less with surface penetration than with surface spreading, because the soil behaves as an odor blanket when sludge is incorporated into it. Between the soil incorporation and soil injection methods, the latter has less odor potential because injection of sludge further reduces the exposed surface area. The only drawback in both of these methods is their limited use during crop growing seasons.

4. Potential Impacts

Odor dispersion from sludge application is similar to that from the holding basins, and the atmospheric dilution capacity is essentially the same. The shapes of equal dilution contours are different and depend upon the shapes of the individual application fields. In the case of spray application, the sprayer gun will be the center of odor emission, but fine aerosols generated by the sprayer may travel great distances downwind and concurrently evaporate. This will cause a shift of odor in a downwind direction, depending on wind speed.

Based on the foregoing considerations, sensitive receptors located near the application fields will be impacted the most by spraying techniques. Affected fields include #27, #28, and #31 through #38. The spraying method is planned to be curtailed in 1976, and would account for only 15% of total sludge application, which will definitely decrease odor problems.

The strength of odor emissions from evaporation of sludge applied to the soil surface and from surface ponding is equal to that from the sludge holding basins. The consequent odor problems are short-term, however, because most odorants in the sludge will be released into the atmosphere within the first week after sludge application. Nevertheless, these short-term impacts may be prolonged and intensified during unfavorable meteorological conditions. The planned 1976 change-over to sludge application by soil penetration methods for 85% of total applications should substantially ameliorate odor problems due to application; problems related to storage in holding basins would remain.

5. Mitigation of Adverse Effects

Mitigative measures associated with sludge application can either reduce source strength or discourage odor transmission from aerosol drift. Reducing spray pressure, emission height, and inclination of the sprayer gun reduces sludge aerosolization, thus reducing odor emission strength. Sludge spraying should, however, be prohibited on windy days and during atmospheric stagnation. The use of surface application methods will eliminate sludge aerosols and their associated odor problems at the application fields.

Odors originating from sludge in the soil can be controlled by a reduction in the surface area of sludge exposed to the atmosphere. Soil incorporation or,better yet, soil injection is considered to be the sludge application method most effective in reducing odor potential.

Sludge ponding in the fields should be disallowed or certainly kept at a minimum. Ponding can be reduced by increasing the number of application runs and allowing one week to elapse between successive runs. Occasional unavoidable ponding should instigate control of odor generation. The MSDGC has applied 74Q7, an odor control product of Pollution Sciences, Inc., to ponding areas, and this practice should be continued.

E. POTENTIAL SURFACE WATER CONTAMINATION

Chemical and biological water quality data collected from various monitoring stations on streams, reservoirs, and runoff basins are analyzed and summarized in this section. The conformance of water quality with applicable standards is examined. The potential adverse impacts resulting from project operations are delineated and appropriate mitigative measures are recommended.

1. Water Quality of Streams

There are 11 water monitoring stations throughout the project area: S1, S2, S3, S19, S20, S21, S27, S29, S31, S32, and S33; their locations are shown in Figure VII-19. A total of 24 water quality parameters are analyzed for each station (MSDGC, 1972a through 1975g).

It is important to distinguish stations measuring background water quality conditions from those affected by project operations. The project actually began in July 1972 when sludge was applied to Fields #3, and #9.

Sludge was applied to Fields # 9 through #38, with the exception of Fields #34, #35, and #36, from July 1972 to July 1975. These fields are primarily located south of Highway 5, as shown by the shaded area in Figure VII-19. Sampling stations S19, S20, S21, S29, S31, S32, and S33, which were unaffected by the project as of July 1975, will represent background stream water quality stations. Station S1, which is upstream from the project site, is also a background station. Station S3 is located on Slug Run, a tributary which is isolated from the application fields, and is therefore considered to be a background station as well.

a. Chemical concentrations - After comparing the water quality data gathered from these 11 stations with the water quality standards for Illinois (see Chapter II), the chemical water quality is summarized in terms of number of observations and violations of standards in Table VII-7.

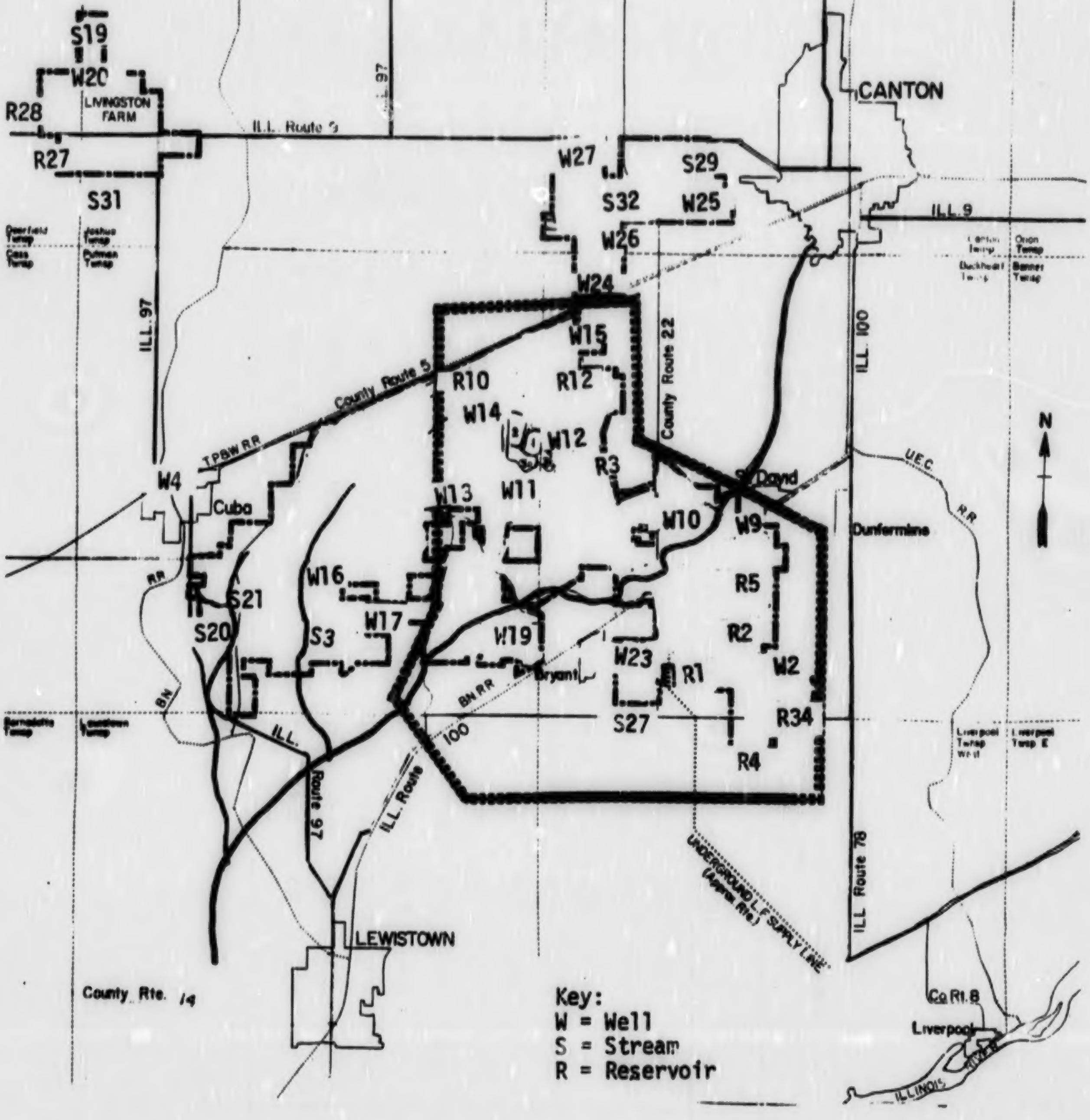

S19
W20
LIVINGSTON FARM
R28
R27
S31
ILL. 97
ILL. Route 9
CANTON
W27
S29
S32
W25
W26
ILL. 9
W24
W15
County Route 5
R10
R12
County Route 22
ILL. 100
W14
W12
R3
N
TPBW RR
W4
Cuba
W13
W11
St. David
W10
W9
Dunfermline
U.E.C. RR
RR
W16
S21
R5
S20
S3
W17
W19
R2
W23
R1
W2
Bryant
BN
BN RR
ILL.
100
S27
R34
R4
Route 97
ILL. Route
ILL. Route 78
UNDERGROUND L.F. SUPPLY LINE
LEWISTOWN
County Rte. 14
Co Rt. 8
Liverpool
ILLINOIS RIVER
Key:
W = Well
S = Stream
R = Reservoir

Figure VII-19. General Area Applied with Sludge and Water Monitoring Stations (MSDGC, 1972a through 1975g).

Table VII-7. Ratio of Violations and Observations Reported at Various Stream Sampling Stations, July 1972 to July 1975 (MSDGC, 1972a through 1975g; General Water Quality Standards for Illinois Waters)

Contaminant / Stream Sampling Station	pH	Cl$^-$	$SO_4^=$	NH_3-N	Cd	Cr	Cu	Fe	Pb	Hg	Mn	Ni	Se	Zn	TDS
S1	0/31	0/31	5/31	12/31	0/31	0/31	11/31	20/31	3/31	0/31	1/31	0/31	0/15	0/31	6/10
S2	0/31	0/31	13/31	5/31	0/31	0/31	11/31	16/31	3/31	0/31	1/31	0/31	0/15	0/31	9/10
S3	0/31	0/31	15/31	1/31	1/31	0/31	1/31	10/31	5/31	1/31	1/31	0/31	0/15	0/31	7/8
S19	0/31	0/31	0/31	0/31	0/31	0/31	4/21	3/31	4/31	1/31	0/31	0/31	0/14	0/31	2/9
S20	0/4	0/4	4/4	4/4	0/4	0/4	0/4	2/4	0/4	0/4	1/4	0/4	0/4	0/4	4/4
S21	0/3	0/3	3/3	4/4	0/4	0/4	0/4	4/4	1/4	0/3	4/4	0/4	0/4	0/4	3/3
S27	0/31	0/31	6/31	0/31	0/31	0/31	5/31	14/31	1/31	0/31	2/31	0/31	0/15	0/31	7/9
S29	0/31	0/31	0/31	0/31	0/30	0/31	5/31	4/31	5/31	1/31	0/31	0/31	0/15	0/31	1/8
S31	0/31	0/31	21/31	0/31	0/31	0/31	7/31	5/31	7/31	1/31	20/31	0/31	0/14	10/31	9/9
S32	0/31	0/31	9/31	0/31	0/31	0/31	4/31	6/31	5/31	5/31	0/31	0/31	0/15	0/31	7/8
S33	0/9	0/9	9/9	5/9	1/9	0/7	1/9	8/9	1/9	0/9	9/9	0/9	0/9	3/9	7/9

The pH values and concentrations of Cl, Cr, Ni, and Se are within standards at all stations. Stations S20, S21, and S33 indicate numerous violations of standards for SO_4, NH_3-N, Fe, Mn, and total dissolved solids (TDS). These stations might be influenced by the surface runoff from a cattle feedlot, effluents from septic tanks in the community of Cuba, seepage from an oxidation pond, and landfill leachate within the project property (see Figure VII-19, page VII-47). In addition, Station S33 reports high concentrations of Cd and Zn, and Station S31 shows violations of SO_4, Cu, Fe, Pb, Mn, Zn and TDS standards. These violations may result from runoff on strip-mined land, but this cannot be confirmed in the absence of a field investigation. Station 27, which is located downstream from application fields 28, 30, 31, 32, and 33, has recorded a number of violations of SO_4, Cu, Fe, Pb, Mn, and TDS standards.

The number of violations reported at Station S1 correlate with those at Station S2. Water quality at Stations S1 and S2 may be influenced by the effluent from the Canton Sewage Treatment Plant. Numerous violations of SO_4, NH_3, Cu, Fe, Pb, and TDS standards have been reported at these two stations. Downstream Station S2 demonstrates better overall water quality than Station S1; instream purification must occur along Big Creek between these two stations. However, cleansing in this stream segment is insufficient to reduce pollutants at Station S2 to acceptable levels. Runoff basins provided for the sludge application fields are not effective in removing dissolved solids. The dissolved solids, containing metals, seem to be discharged into this segment of the creek.

b. Fecal coliform concentrations - The only biological water quality parameter measured at these monitoring stations is fecal coliform concentration. Fecal coliforms, while non-pathogenic, indicate that pathogenic organisms of fecal origin may be present in the water. The number of observations, geometric mean, maximum, and minimum fecal coliform concentrations at all stream stations are given in Table VII-8. Geometric means at stations S1,

Table VII-8. Fecal Coliform Concentrations in Streams, July 1972 to July 1975 (MSDGC, 1972a through 1975g)

Stream Sampling Station	Number of Observations	Fecal Coliform Concentration per 100 ml Geometric Mean*	Maximum	Minimum
S1	25	10,177	87,000	100
S2	26	3,353	47,000	100
S3	25	194	1,200	10
S19	26	566	66,000	40
S20	4	1,032	42,000	30
S21	4	14	100	0
S27	24	1,267	28,000	40
S29	25	628	5,000	0
S31	26	155	10,370	0
S32	26	87	1,300	0
S33	9	346	6,900	60

*Illinois standard = 200 max.

S2, S19, S20, S27, S29, and S33 exceed the Illinois standard of 200 per 100 ml. This is probably due to contamination by human or animal waste in effluents from the sewage treatment plant and septic tanks, and in runoff from cattle feedlots.

Fecal coliform concentrations generally decrease between Stations S1 and S2. This is demonstrated by the chronological plotting of fecal coliforms for both stations as shown in Figure VII-20. Assuming the flow velocity in Big Creek to vary from 0.3 to 1.0 fps, the pollution time in residence between the two stations ranges from 9.5 to 32 hours.

Using the geometric means in Table VII-8 (page VII-50) and assuming a logarithmic linear die-off function, this residence time corresponds to a coliform half-life of 6 to 20 hours. This rate includes the dilution effect of runoff along this 6.5-mile segment of Big Creek. The actual die-off rate must, therefore, be lower. Both stations experienced a higher level of fecal coliforms in the summer, presumably because warm weather favors the survival of bacteria. In October 1973 and February 1975, fecal coliform counts at Station S2 were higher than at Station S1. Therefore, other sources of fecal pollution may exist between these two stations.

2. Water Quality of Reservoirs

Ten stations are established to monitor the water quality of reservoirs; they are designated R1, R2, R3, R4, R5, R10, R12, R27 (or RN27), and R34, and their locations are shown in Figure VII-19 (page VII-47). A total of 27 water quality parameters are measured; the data are presented in Table VII-9.

a. Chemical and fecal coliform concentrations - Strip-mine lakes in central Missouri were studied by Campbell and Lind (1969) for long-term aging or successional change by stages. For the purposes of their discussion, lakes were identified by letter:

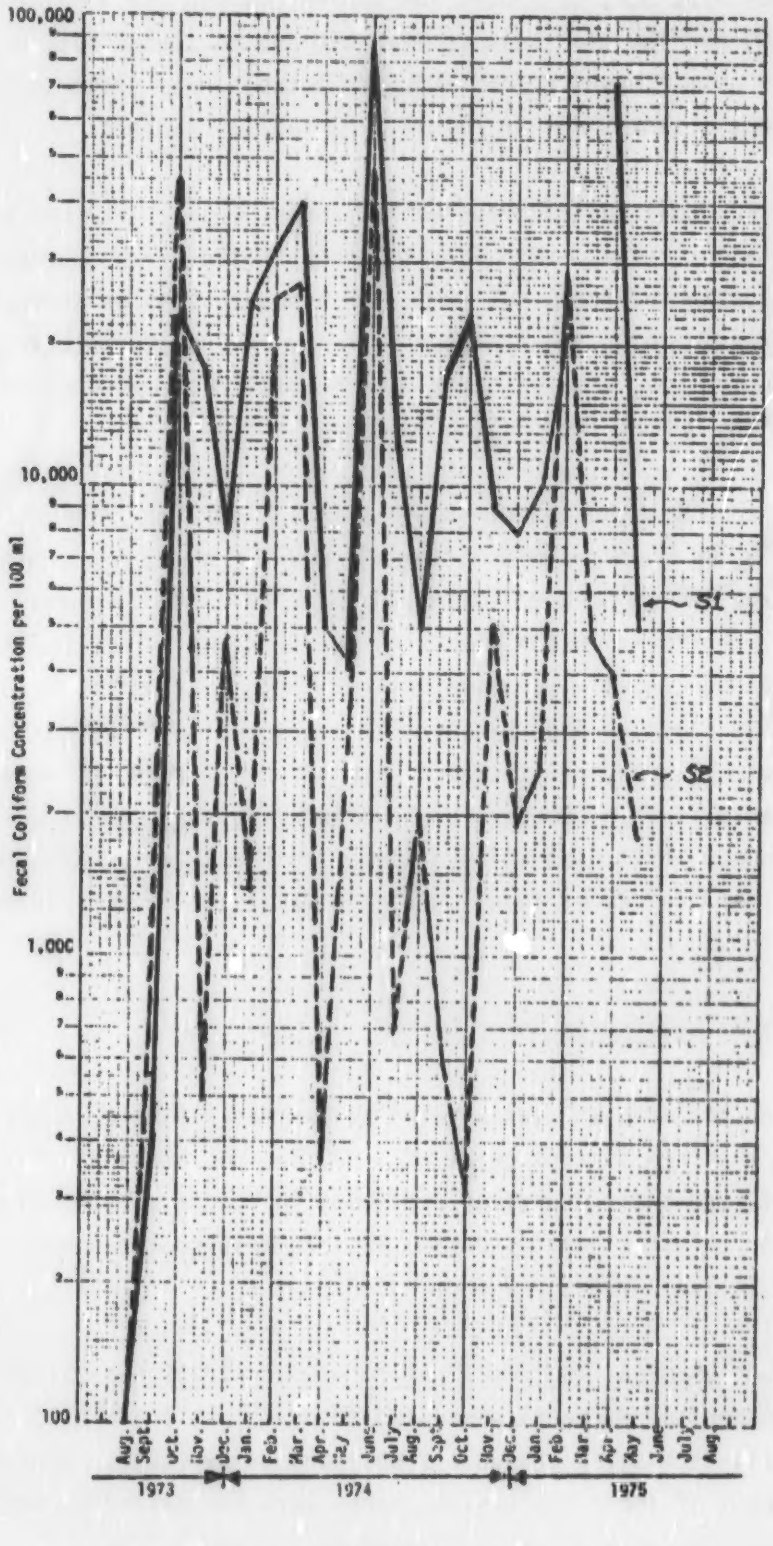


Figure VII-20. Variation of Fecal Coliform Concentrations with Time for Stations S1 and S2 (MSDGC, 1972a through 1975g).

Table VII-9. Water Quality of Reservoirs (MSDGC, 1972a through 1975g; Campell and Lind, 1969; General Water Quality Standards for Illinois' Waters)

Water Quality Parameter and Unit	Reservoir Samples				Strip Mine Lakes of Type B	Illinois Surface Water Quality Standards
	July-Dec. 1972	Jan.-Dec. 1973	Jan.-Dec. 1974	Jan.-July 1975		
pH	6.9-10.0	7.3-8.9	7.3-9.0	6.9-9.0	6.1-8.2	6.5-9.0
Total P (mg/l)	0-1.20	0.02-0.73	0-2.80	0.01-0.47	--	≤0.05
Cl (mg/l)	1-30	5-20	2-312	4-130	--	≤500
SO_4 (mg/l)	4-1,508	16-781	13-1,160	40-1,030	134-245	≤500
N-Kjeldahl (mg/l)	0-4.4	0-2.4	0-4.5	0-2.3	--	--
NH_3-N (mg/l)	0.1-1.5	0-1.07	0-2.0	0-1.0	--	≤1.5
NO_3+NO_3-N (mg/l)	0-1.10	0-8.30	0-6.30	0.01-8.48	--	--
Alkalinity (as $CaCO_3$) (mg/l)	70-580	80-500	56-530	30-900	49-92	--
Conductivity (mho)	120-2,500	300-3,340	570-2,300	300-2,000	--	--
Ca (mg/l)	9-360	45-367	45-550	20-418	39.5-63.0	--
K (mg/l)	0-13	1-8	2-10	1-10	5.7-7.5	--
Na (mg/l)	1-535	9-229	9-265	9-219	6.0-7.3	--
Al (mg/l)	--	0-3.77	0-4.0	0-4.0	0.001-0.058	--
Cd (mg/l)	0-0.1	0-0.02	0-0.03	0-0.02	--	≤0.05
Cr (mg/l)	0-0.11	0-0.02	0-0.03	0-0.04	--	Cr(+6) ≤ 0.05 Cr(+3) ≤ 1.0
Cu (mg/l)	0-0.16	0-0.13	0-0.08	0-0.43	--	≤0.02
Fe (mg/l)	0-3.6	0-1.9	0-9.2	0-2.4	0.0-0.024	≤1.0
Pb (mg/l)	0-0.31	0-0.33	0-0.27	0-0.13	--	≤0.1
Mg (mg/l)	10-483	34-132	35-162	20-137	17.1-25.6	--
Mn (mg/l)	0-1.19	0-1.22	0-1.55	0-0.98	0.08-2.1	≤1.0
Hg (mg/l)	0-0.9	0-0.8	0-3.0	0-0.88	--	≤0.5
Ni (mg/l)	0-0.38	0	0-0.1	0-0.3	--	≤1.0
Zn (mg/l)	0-0.6	0	0-0.4	0-0.2	0.05-0.07	≤1.0
T.S.S. (mg/l)	--	--	0-231	1-187	--	--
T.D.S. (mg/l)	--	--	422-2,092	189-6,940	--	≤1,000
Fecal Coliforms (1/100 ml)	0->7,000	0-7,600	0-1,500	0-660	--	≤200 (geometric mean)
D.O. (mg/l)	6.0-20.0	5.6-15.6	8.4-15.3	4.9-14.2	--	≥5 (anytime)

A1, A2, and A3 are acid; B and D are neutral or slightly alkaline. Lake A represents the most acidic stage, resulting from continued oxidation of sulfur-bearing waste coal in the watershed, and Lake D represents the alkaline stage.

The most obvious changes associated with the aging of strip-mine lakes pertain to acid-base relationships. Decline in potential free acidity as lakes age is related to the appearance of bicarbonate alkalinity. In addition, decreasing specific conductance and declining concentrations of sulfate, calcium, magnesium, potassium, and sodium with increasing pH indicate aging of strip-mine lakes. The reservoirs within the MSDGC project property have water most similar in quality to Lake B, which represents a relatively well-aged strip-mine lake. To assess the effects of abandoned strip mines on lake or reservoir water quality, the data collected at the project site are compared to those for Type B strip-mine lakes.

In general, the pH values, alkalinity, and concentrations of metals in these reservoirs are somewhat higher than average for those of strip-mine lakes, though still within their range. Reservoirs within the project property are relatively richer in mineral contents. The comparison shows that project-area lakes are sufficiently aged to support substantial aquatic life, and they are more vulnerable to high nutrient inputs and eutrophication than the less-aged, acidic strip-mine lakes.

The pH values and ammonia nitrogen levels in these reservoirs generally conform to Illinois water quality standards. Concentrations of chlorides and metals such as Cd, Cr, Ni, and Zn are normally within state standards. These reservoirs do, however, exhibit high levels of inorganic nitrogen, total phosphorus, sulfate, Cu, Fe, Pb, Mn, and Hg, which violate Illinois standards. High salt content often increases the level of total dissolved solids above the standard. High dissolved solids may be attributed to surface runoff from strip-mined areas and sludge application fields, or release of dissolved bottom sediments in the reservoirs. Reservoir sediments may contain large amounts of strip-mine spoil resulting from rain downwash. Samples of reservoir bottom sediments are unavailable. This hypothesis could be tested with further investigation and monitoring.

Fecal coliform concentrations in all reservoirs are generally low, indicating that the treated and aged sludge applied to the project site has a low fecal coliform level and/or the runoff basins in the application fields are effective in removing fecal bacteria. Nevertheless, high levels of fecal coliforms are found sporadically.

b. Dissolved oxygen concentrations - Dissolved oxygen (D.O.) concentrations determine the capacity of a water body to support aquatic life. The State of Illinois specifies that a minimum of 6 mg/l of D.O. must be maintained for 16 hours of a 24-hour period, and a minimum of 5 mg/l of D.O. must be maintained at all times. The D.O. status of reservoirs R1, R2 and R3 are discussed below. Data are unavailable for the other reservoirs.

D.O. levels, average water temperatures, and average theoretical saturation values of D.O. in the three reservoirs are presented in Figure VII-21. As the data indicate, D.O. levels are generally higher than the minimum standard of 5 mg/l. The D.O. levels of all three reservoirs form a typical seasonal pattern, with D.O. peaking in winter and at a minimum in summer. This cyclic pattern is, as expected, opposite to the seasonal variation of reservoir temperature. D.O. levels are close to the average theoretical saturation values, and are therefore predominantly influenced by water temperature and the reservoir mixing characteristics. The reservoirs probably have not received large inputs of oxygen-demanding pollutants such as carbonaceous and nitrogeneous organic materials.

During May 1973 and July 1975, D.O. levels dropped below 6 mg/l in Reservoir R1, which receives runoff basin effluents from sludge application Fields #26, #27, #28, and #30. Sludge was not applied to these fields until August 1974. Runoff retention basin B-30-2

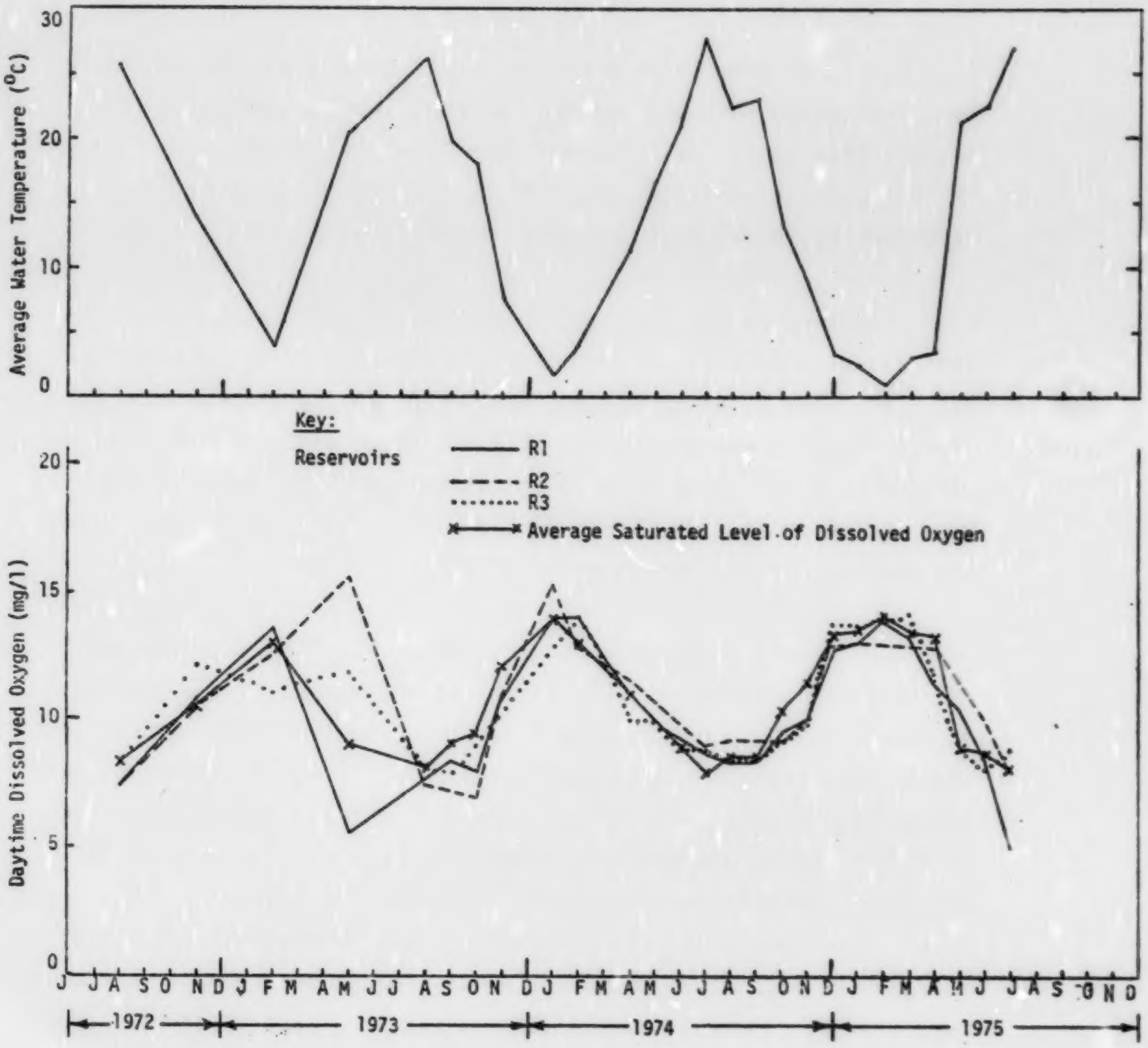


Figure VII-21. Reservoir Water Temperature and Level of Dissolved Oxygen (D.O.) (MSDGC, 1972a through 1975g; and Enviro Control, Inc. 1976).

discharged into Reservoir R1 after the reservoir water was sampled on July 9, 1975. Therefore, no connection between observed low D.O. concentrations in Reservoir R1 and the project operation can be established.

During the summer, when ambient temperatures are high and D.O. saturation levels are low, nighttime D.O. levels may be much lower than daytime levels. This is attributable to the continued depletion of D.O. by planktonic respiration while photosynthetic oxygen regeneration is absent. Nighttime monitoring of D.O. is therefore essential to complete the assessment of possible environmental impacts resulting from project operations.

3. Water Quality and Capacity of Runoff Basins

More than 50 runoff retention basins have been constructed within the project property as of July 1975. With the exception of Field #38, on which sludge was applied in October 1974, all fields receiving or scheduled to receive sludge are provided with at least one basin. Each runoff basin is coded with the same number as the field it serves, with a sub-number when more than one basin is provided for a particular field. For example, basin B-20-3 represents Basin #3 of Field #20.

a. Effluent quality - The operating permit issued by the Illinois EPA specifies effluent standards for total suspended solids (TSS), biological oxygen demand (BOD), and fecal coliforms (as discussed in Chapter IV):

- Arithmetic mean of TSS shall not exceed 66.7 mg/l
- Arithmetic mean of BOD shall not exceed 6.75 mg/l
- Geometric mean of fecal coliforms shall not exceed 494.3 per 100 ml.

Effluent quality of a runoff basin is analyzed whenever there is a discharge. The discharge of effluents from the runoff basin is necessary to reduce the water level even in the absence of sludge application. The arithmetic or geometric mean, maximum, and minimum levels of TSS, BOD, and fecal coliforms in each runoff basin are presented in Table VII-10.

Discharge from runoff basins occurs intermittently and rarely more than once a month. Therefore, the effects of a discharge upon the receiving reservoir or creek probably diminish to insignificant levels when the subsequent discharge is made. The process of averaging effluent quality as required by the state standards may be inappropriate; very inferior effluents were discharged to receiving waterways or water bodies, while their averaged water quality was within the standards. As shown in Table VII-10, these substandard effluents contained TSS as high as 644 mg/l, BOD as high as 73 mg/l, and fecal coliform counts as high as 5,000 per 100 ml. Such peak concentrations could cause fish kills or other irreversible biotic impacts, primarily due to depletion of dissolved oxygen.

b. Storm runoff capacities - Runoff basins were constructed to provide a retention capacity for runoff from a 100-year storm. The purpose of the basins is to retain runoff from application fields for the length of time required to meet standards before the runoff water is discharged. Substandard basin water may be recycled by pumping to the application field.

The effectiveness of runoff basins in containing 100-year storm runoff can be examined by comparing the design capacity of the basins with the anticipated volume of storm runoff. Table VII-11 summarizes the design capacity of each retention basin and storm runoff volumes for 25-year and 100-year storms. The 24-hour runoff volumes for 25-year and 100-year storms are calculated on the assumption of no percolation and no evapotranspiration of rain water. These assumptions result in slightly overestimating storm runoff, which causes the evaluation of retention basin effectiveness to be conservative.

Table VII-10. Effluent Quality of Runoff Retention Basins (MSDGC, 1972a through 1975g; and Enviro Control, Inc., 1976)

	Parameter	Effluent Standard	Runoff Retention Basin										
			B-1-1	B-2-1	B-2-2	B-2-3	B-3-1	B-4-1	B-4-2	D-5-1	B-6-1	B-7-1	B-7-2
Total Suspended Solids	No. of Observations	Arithmetic mean of TSS shall not exceed 66.7 mg/l	5	4	8	9	25	16	1	14	3	2	6
	No. of Violations		0	0	1	2	7	1	0	2	1	2	0
	Mean (mg/l)		22.2	9	35.5	33.3	49.1	13.7	10	86.5	78	92.5	21.3
	Maximum (mg/l)		36	16	43	22	353	220	--	644	184	93	52
	Minimum (mg/l)		9	4	10	7	1	1	--	5	8	92	8
Biological Oxygen Demand	No. of Observations	Arithmetic mean of BOD shall not exceed 6.75 mg/l	5	4	8	8	19	12	1	13	2	--	4
	No. of Violations		3	1	3	1	9	6	1	10	0	--	2
	Mean (mg/l)		9.2	7.3	9.1	4.5	12.9	10.9	21	11.2	2.5	--	7
	Maximum (mg/l)		13	16	29	8	66	23	--	32	3	--	11
	Minimum (mg/l)		4	2	2	2	2	1	--	1	2	--	5
Fecal Coliforms	No. of Observations	Geometric mean of fecal coliforms shall not exceed 494.3 per 100 ml	5	4	8	9	26	12	1	13	2	1	4
	No. of Violations		0	0	0	0	2	0	0	1	1	0	0
	Geo. Mean (1/100 ml)		23	14	16	22	74	12	80	31	31	180	25
	Maximum (1/100 ml)		60	40	20	130	2,000	180	--	1,300	1300	--	130
	Minimum (1/100 ml)		<10	<10	<10	2	2	<10	--	2	2	--	<10

	Parameter	Effluent Standard	Runoff Retention Basin										
			B-7-3	B-8-1	B-8-2	B-9-1	B-9-2	B-9-3	B-10-1	B-10-2	B-11-1	B-12-1	B-13-1
Total Suspended Solids	No. of Observations	Arithmetic mean of TSS shall not exceed 66.7 mg/l	12	12	7	21	11	3	3	1	8	5	4
	No. of Violations		1	4	3	0	3	1	0	0	4	0	0
	Mean (mg/l)		32.6	49.4	122.1	30.8	43.1	77.3	29	41	58.6	29	36.3
	Maximum (mg/l)		127	101	148	64	94	218	38	--	89	50	49
	Minimum (mg/l)		4	5	17	3	11	6	22	--	28	8	21
Biological Oxygen Demand	No. of Observations	Arithmetic mean of BOD shall not exceed 6.75 mg/l	10	10	6	16	4	--	3	1	8	5	4
	No. of Violations		4	5	1	6	0	--	2	0	8	3	3
	Mean (mg/l)		6.3	6.5	5	7.9	4.5	--	7.7	6	15	10	9.3
	Maximum (mg/l)		14	14	12	22	5	--	11	--	34	22	14
	Minimum (mg/l)		2	2	2	1	3	--	5	--	7	2	3
Fecal Coliforms	No. of Observations	Geometric mean of fecal coliforms shall not exceed 494.3 per 100 ml	11	11	6	19	7	1	3	1	8	5	4
	No. of Violations		0	1	0	4	1	0	0	0	0	0	0
	Geo. Mean (1/100 ml)		26	26	14	46	85	<10	17	<10	25	14	21
	Maximum (1/100 ml)		160	520	130	840	500	--	50	--	150	30	190
	Minimum (1/100 ml)		2	<10	2	2	2	--	<10	--	<10	<10	<10

Table VII-10. Continued

Parameter		Effluent Standard	Runoff Retention Basin										
			B-13-2	B-14-1	B-15-1	B-16-1	B-17-1	B-17-2	B-19-1	B-20-1	B-20-2	B-20-3	B-21-1
Total Suspended Solids	No. of Observations	Arithmetic mean of TSS shall not exceed 66.7 mg/l	2	0	6	8	9	4	5	13	7	7	4
	No. of Violations		0	--	2	0	2	2	2	0	3	1	0
	Mean (mg/l)		16	--	35.5	15.3	40.1	40.1	63.8	79.8	108.6	34.7	26.3
	Maximum (mg/l)		26	--	76	30	153	60	100	59	312	37	62
	Minimum (mg/l)		6	--	10	2	1	31	20	3	17	1	6
Biological Oxygen Demand	No. of Observations	Arithmetic mean of BOD shall Not exceed 6.75 mg/l	2	0	6	8	6	3	4	10	6	4	2
	No. of Violations		0	--	3	7	1	2	2	5	4	1	0
	Mean (mg/l)		4	--	8.2	10.3	3.5	16.7	7.5	6.3	18.8	5	2
	Maximum (mg/l)		5	--	17	20	7	38	12	10	73	7	3
	Minimum (mg/l)		3	--	3	3	2	3	3	3	2	3	1
Fecal Coliforms	No. of Observations	Geometric mean of fecal coliforms shall not exceed 494.3 per 100 ml	2	0	6	8	9	4	4	11	6	5	5
	No. of Violations		0	--	1	0	0	0	0	0	1	1	1
	Geo. Mean (1/100 ml)		33	--	69	22	17	15	34	15	32	21	36
	Maximum (1/100 ml)		190	--	5,000	160	150	50	70	80	2,800	1,000	2,800
	Minimum (1/100 ml)		<10	--	<10	<10	<10	<10	<10	<10	2	2	2

Parameter		Effluent Standard	Runoff Retention Basin										
			B-22-1	B-22-2	B-23-1	B-25-1	B-25-2	B-26-1	B-26-2	B-27-1	B-27-2	B-28-1	B-30-1
Total Suspended Solids	No. of Observations	Arithmetic mean of TSS shall not exceed 66.7 mg/l	20	12	0	3	1	5	6	4	4	5	5
	No. of Violations		0	4	--	0	0	0	0	0	0	0	0
	Mean (mg/l)		16.4	81.9	--	15.3	6	23.6	17	11.8	13.3	23.4	12
	Maximum (mg/l)		34	188	--	25	--	45	32	26	19	61	17
	Minimum (mg/l)		4	2	--	9	--	3	8	5	6	4	5
Biological Oxygen Demand	No. of Observations	Arithmetic mean of BOD shall not exceed 6.75 mg/l	11	6	0	3	1	5	6	4	4	5	5
	No. of Violations		7	3	--	0	0	2	3	0	0	3	2
	Mean (mg/l)		8.5	7.2	--	5.7	4	6.6	6.8	5	5.75	8.6	6.4
	Maximum (mg/l)		16	11	--	6	--	11	12	5	7	14	9
	Minimum (mg/l)		3	3	--	5	--	4	4	5	4	4	4
Fecal Coliforms	No. of Observations	Geometric mean of fecal coliforms shall not exceed 494.3 per 100 ml	16	11	0	3	1	5	6	4	4	5	5
	No. of Violations		0	0	--	0	0	0	0	1	0	0	0
	Geo. Mean (1/100 ml)		16	49	--	<10	<10	12	26	71	<10	21	<10
	Maximum (1/100 ml)		320	400	--	--	--	20	100	2,600	--	130	--
	Minimum (1/100 ml)		2	<10	--	--	--	<10	<10	<10	--	<10	--

Table VII-10. Continued

	Parameter	Effluent Standard	Runoff Retention Basin										
			B-30-2	B-31-1	B-32-1	B-33	B-34-1	B-34-2	B-35-1	B-36-1	B-37-1		
Total Suspended Solids	No. of Observations	Arithmetic mean of TSS shall not exceed 66.7 mg/l	6	0	0	0	0	0	0	0	0		
	No. of Violations		0	--	--	--	--	--	--	--	--		
	Mean (mg/l)		16.5	--	--	--	--	--	--	--	--		
	Maximum (mg/l)		28	--	--	--	--	--	--	--	--		
	Minimum (mg/l)		6	--	--	--	--	--	--	--	--		
Biological Oxygen Demand	No. of Observations	Arithmetic mean of BOD shall not exceed 6.75 mg/l	6	0	0	0	0	0	0	0	0		
	No. of Violations		2	--	--	--	--	--	--	--	--		
	Mean (mg/l)		6.3	--	--	--	--	--	--	--	--		
	Maximum (mg/l)		9	--	--	--	--	--	--	--	--		
	Minimum (mg/l)		4	--	--	--	--	--	--	--	--		
Fecal Coliforms	No. of Observations	Geometric mean of fecal coliforms shall not exceed 494.3 per 100 ml	6	0	0	0	0	0	0	0	0		
	No. of Violations		0	--	--	--	--	--	--	--	--		
	Geo. Mean (1/100 ml)		<10	--	--	--	--	--	--	--	--		
	Maximum (1/100 ml)		--	--	--	--	--	--	--	--	--		
	Minimum (1/100 ml)		--	--	--	--	--	--	--	--	--		

Table VII-11. Capacity of Runoff Retention Basins and Volume of 24-Hour Storm Runoff (MSDGC, 1972c through 1972g and 1973i through 1973k; Enviro Control, Inc., 1976)

Field Number	Runoff Retention Basins: Basin	Runoff Retention Basins: Capacity Per Basin (acre-ft)	Runoff Retention Basins: Capacity Per Field (acre-ft)	24-Hr. Runoff Assuming No Ground Percolation or Evapotranspiration (acre-ft): 25-Yr. Storm	24-Hr. Runoff Assuming No Ground Percolation or Evapotranspiration (acre-ft): 100-Yr. Storm
1	B-1-1	24.4	24.4	20.1	25.0
2	B-2-1	21.5	28.5	22.7	28.3
	B-2-2	4.1			
	B-2-3	2.9			
3	B-3-1	NA	NA	17.9	22.3
4	B-4-1	6.2	32.1	35.0	43.5
	B-4-2	25.9			
5	B-5-1	15.3	15.3	13.1	16.3
6	B-6-1	6.6	6.6	6.6	8.2
7	B-7-1	5.9	38.9	48.1	59.8
	B-7-2	16.0			
	B-7-3	17.0			
8	B-8-1	25.2	31.6	31.1	38.6
	B-8-2	6.4			
9	B-9-1	NA	>18.6	76.5	95.2
	B-9-2	13.7			
	B-9-3	4.9			
10	B-10-1	21.5	44.5	41.1	51.2
	B-10-2	23.0			
11	B-11-1	8.0	8.0	9.2	11.4
12	B-12-1	11.0	11.0	11.8	14.7
13	B-13-1	9.5	48.5	15.7	19.6
	B-13-2	39.5			
14	B-14-1	14.3	14.3	30.6	38.1
15	B-15-1	10.5	10.5	9.6	12.0
16	B-16-1	70.3	70.3	65.6	81.6
19	B-19-1	NA	NA	16.6	20.7
20	B-20-1	NA	NA	49.9	62.0
	B-20-2	NA			
	B-20-3	NA			
21	B-21-1	NA	NA	17.1	21.2
22	B-22-1	NA	NA	22.7	28.3
	B-22-2	NA			
23	B-23-1	14.9	14.9	9.6	12.0
25	B-25-1	6.9	14.4	16.6	20.7
	B-25-2	7.5			
26	B-26-1	13.8	22.6	28.0	34.8
	B-26-2	8.8			
27	B-27-1	17.5	24.6	18.8	23.4
	B-27-2	7.1			
28	B-28-1	13.5	13.5	13.6	16.9
29	B-29-1	14.9	14.9	17.1	21.2
30	B-30-1	7.2	27.3	30.2	37.5
	B-30-2	20.1			
31	B-31-1	9.3	9.3	8.1	10.1
32	B-32-1	15.8	15.8	14.9	18.5
33	B-33	*			
34	B-34-1	26.4	38.7	31.3	39.0
	B-34-2	12.3			
35	B-35-1	14.2**	93.0	79.4	98.8
36	B-36-1	78.8			
37	B-37-1	35.7	35.7	30.1	37.5
38	NA	NA	NA	23.7	29.5
39	B-39-1	14.6	14.6	18.4	22.9
40	B-40-1	30.7	30.7	35.9	44.6
41	B-41-1	23.3	23.3	24.1	29.9
42	B-42-1	33.3	57.7	70.8	88.2
	B-42-2	24.4			
43	B-43-1	23.1	23.1	25.8	32.1
44	B-44-1	11.6	11.6	14.9	18.5
45	B-45-1	48.1	48.1	63.9	79.4
47	B-47-1	12.5	12.5	13.1	16.3

Note: NA = Not Available
*Field #33 drains its runoff to Retention Basin B-32-1 of Field #32.
**Field #35 drains its eastern portion of runoff to Retention Basin B-36-1 of Field #36.

As discussed in Chapter IV, the vertical permeability of soils within the project area is estimated by laboratory tests to range from 10^{-5} to 10^{-9} cm/sec. According to Casagrande's classification of soils by permeability, these soils are impervious, nondraining, or poorly draining. Areas consisting of broken shale and sandstone slabs or blocks may possess a permeability as high as 10^{-1} cm/sec, at which water flows with little resistance. However, construction is not allowed on these areas. In any case, stormwater is almost totally drained to the retention basins. Localized ponding of rain water in the fields may tend to reduce total runoff volume, but is believed to be of minor significance. Because the drainage areas of the application fields are relatively small, the runoff concentration times are relatively short, and little evapotranspiration occurs. The preceding argument seems to justify the assumptions on which storm runoff calculations are based.

From the available data, only the retention basins for Fields #1, #2, #23 and #27 will be able to contain 25-year and 100-year storm runoff. Retention basins for Fields #5, #6, #8, #10, #15, #16, and #31 through #37 will be able to contain 25-year but not 100-year storm runoff. The retention basins for the remaining 18 fields do not have the capacity to contain even 25-year storm runoff.

The preceding analysis is based on the further assumptions that the basins are completely empty prior to each storm, and the basin capacities are not diminished by sedimentation of suspended solids from previous storm runoff. The effectiveness of a runoff basin is seriously impaired when a storm occurs before the basin is entirely empty. Furthermore, emptying the basins before a predicted storm may cause bottom sediments containing sludge particles to be discharged to the receiving water.

4. Potential Impacts

Pollutant concentrations violating Illinois water quality standards have been recorded at both background and non-background stream quality monitoring stations with respect to sulfate, copper, iron, lead, manganese, and total dissolved solids. Runoff over strip-mined areas and sludge application fields are most likely responsible for poor stream water quality. Substandard water quality has also been documented for reservoirs at the project site. Reservoir water quality parameters registering below state standards include sulfate, copper, iron, lead, manganese, mercury, and total dissolved solids; these violations generally parallel those for stream water.

Many runoff basins with inadequate capacity for containing 25-year and 100-year storm runoff are particularly ineffective in removing suspended solids from storm runoff. Numerous violations of effluent standards for total suspended solids and biological oxygen demand show that the runoff retention basins have been ineffective, resulting in siltation and excess dissolved oxygen depletion in the receiving waterways and reservoirs. The levels of total phosphorous and inorganic nitrogen in reservoir waters are high, which is attributable to surface runoff and substandard effluents from runoff retention basins. Continuous nutrient inputs are suspected of causing eutrophication of the reservoirs and their receiving waterways, and present a threat to associated aquatic life.

5. Mitigation of Adverse Effects

The effectiveness of runoff retention basins must be upgraded so that effluents meet required standards for total suspended solids and biological oxygen demand. Retarding runoff velocity and erosion by planting grass, adequate recycling of substandard basin effluents, increasing the capacity of runoff basins, providing additional basins, or combinations of these measures is necessary to achieve required effluent quality.

Analyses of the nutrient concentrations in effluents from runoff basins must be performed to determine nutrient inputs into receiving waterways and reservoirs. These data will aid in estimating the eutrophication potential in receiving waters. Whenever high fecal coliform counts or dissolved oxygen levels are reported in stream or reservoir water samples, the responsible sources must be identified to ensure the effective performance of the control measures.

F. POTENTIAL GROUNDWATER CONTAMINATION

Groundwater quality must be assessed at wells and springs. The quality of samples collected from 26 wells and one spring within the project area is discussed in this section, followed by an assessment of impacts and recommended mitigative measures.

1. Water Quality of Springs and Wells

The locations of wells and springs used for monitoring groundwater quality are shown in Figure VII-19 (page VII-47). From the discussion of groundwater hydrology in Chapter IV, the well and spring stations can be categorized as either background stations or stations where groundwater may be affected by project operations. The background stations lie outside of the portion of the groundwater system associated with the project as of July 1975. Pollutant concentrations at the non-background stations are possibly affected by seepage or percolation from upstream reservoirs or the sludge application fields. Fourteen wells are classified as background stations, and 11 wells and the one spring are classified as non-background. Possible influences of application fields or reservoirs on groundwater quality at each non-background station are presented in Table VII-12.

More than 25 water quality parameters are analyzed for each sample. Trends in nitrite and nitrate nitrogen concentrations (NO_2+NO_3 - N) for each well or spring are discussed below, followed by a discussion concerning trace elements.

a. Nitrite and nitrate concentrations - The nitrite and nitrate nitrogen concentration in each well or spring is plotted from August 1973 to May 1975 (see Appendix C). Trends in these concentrations were analyzed by the least square method. Both background and non-background stations have recorded trends of increasing, decreasing, or constant nitrite and nitrate levels. Only non-background wells W8 and W10 report concentrations in excess of

Table VII-12. Classification of Monitoring Wells
(Enviro Control, Inc., 1976)

Wells Representing the Background Conditions

Well	Project Relationship
W1	Upstream from the project area.
W4	In the community of Cuba and upstream from the project area.
W6	No nearby fields or fields upstream.
W15	No fields upstream.
W16	No fields nearby or upstream in operation yet.
W17	Probably on or near groundwater ridge.
W18	Probably on or near groundwater ridge, and no fields upstream.
W19	No fields nearby or upstream in operation yet.
W20	No fields nearby or upstream in operation yet.
W21	Probably on or near groundwater ridge, and no fields upstream.
W24	No fields nearby or upstream in operation yet.
W25	No fields nearby or upstream in operation yet.
W26	No fields nearby or upstream in operation yet.
	No fields nearby or upstream in operation yet.

Wells Possibly Affected by Project Operations

Well	Project Relationship
W2	Possibly affected by Reservoir R2, and Fields #25, #27, and #38.
W7	Possibly affected by Fields #26 and #38.
W8	Possibly affected by Fields #20 and #21.
W9	Possibly affected by Field #19.
W10	Possibly affected by Field #24.
W11	Possibly affected by sludge holding basins; Fields #3 through #9, and #17; and Reservoirs R10 and R12.
W12	Same as W11.
W13	Same as W11, and additionally affected by Field #2.
W14	Possibly affected by Fields # 6 through #9, and #17; and Reservoir R10.
W22	Possibly affected by Fields # 27, #37, and #38; and Reservoirs R2 and R4.
W23	Possibly affected by Field #31.
Spring	Possibly affected by Field #10.

10 mg/l, which is recommended as the maximum level by the U.S. Public Health Service (U.S. Public Health Service, 1962, 1969). According to extrapolated upward trends, wells W4 and W20 could acquire nitrite and nitrate nitrogen levels higher than 10 mg/l after the next 20 years. It must be noted that Well W4 is located in Cuba and is possibly affected by community pollution sources.

Wells W8 and W10, possibly contaminated by sludge application to Fields #20, #21 and #24, could have nitrite and nitrate nitrogen levels as high as approximately 75 and 145 mg/l, respectively, by mid-1995. The projection of W8 well water quality may not be reliable because Well W8 has consistently low levels of nitrite and nitrate nitrogen, with the exception of a spike between January and May 1975; a similar condition exists in Well W2. Certainly a longer monitoring period would be required to confirm the upward trends in these wells.

The fluctuation in nitrite and nitrate nitrogen levels does not seem to follow any particular pattern. For wells conceivably affected by project operations, the variations in nitrite and nitrate levels do not correlate with project activities. In addition, the levels are generally lower than 0.2 mg/l, except for Well W10 which possesses consistently high values. These findings suggest that a large portion of nitrogen in the applied sludge is fixed by soil molecules, converted and released as ammonia gas, or taken up by crops for biosynthesis. Apparently, little soluble nitrogen is available for leaching into the groundwater system. Wells W11, W12, and W13, conceivably vulnerable to seepage from holding basins, have consistently shown less than 0.2 mg/l of nitrite and nitrate nitrogen. This indicates that the clay linings in the four basins have been effective.

The possible effects of increasing application rates or accumulation of sludge in the fields on groundwater nitrogen levels cannot be assessed at this early stage of project development. Data are not sufficient for analysis of trends, and long-term monitoring of groundwater quality is required to establish the relationship between project operations and the nitrite and nitrate nitrogen level. Study of the movements of labeled nitrogen compounds or isotopes in the soil and in the groundwater system would assist in this assessment.

b. Trace element and other concentrations - Variations in groundwater constituents are shown in Table VII-13. The range of variation is given for seven calendar periods, either before or during the sludge application season. The well reporting the maximum level of a given constituent is indicated in parentheses, and underlined well numbers indicate those wells possibly affected by sludge application.

The pH values, alkalinity, conductivity, and concentrations of total phosphorus, SO_4, Ca, K, Na, Al, Fe, Mg, Mn, Hg, Ni, Se, and fecal coliforms remain close to the 1971 and 1972 baseline conditions (see Chapter IV). Recent concentrations of Cd, Cr, Cu, Pb and Zn are lower than the baseline concentrations. In 1971 and 1972, 40% of the wells tested contained excessively high levels of chemical constituents. When retested between 1973 and 1975, after the project had begun, the statistic was the same. Groundwater constituents are, therefore, probably influenced by sources unrelated to the project.

2. Potential Impacts

Apparently most groundwater constituents have been little influenced by project operations at this early stage of project development. The variations in their concentrations are influenced primarily by the geochemical characteristics of abandoned strip mines, such as heavy metals in exposed black shale. The variations in groundwater quality at both background and non-background stations are comparable. Therefore, soils are probably functioning well as a

Table VII-13. Concentrations of Various Constituents in Groundwater (MSDGC, 1972 a through 1975 g)

Water Quality Parameter and Unit		First Quarter 1973 (before sludge application)	August 1973 (during 1973 sludge application season)	April 1974 (before 1974 sludge application season)	June 1974 (during 1974 sludge application season)	August 1974 (during 1974 sludge application season)	April 1975 (before 1975 sludge application season)	July 1975 (during 1975 sludge application season)
pH		7.0-7.9	7.0-9.9	6.6-8.1	7.1-7.8	6.9-7.7	6.9-8.1	7.3-8.3
Total P	mg/l	0.04-0.95 (W7)	0.07-0.65 (W4)	0.04-0.87 (W24)	0-0.29 (W10)	0.02-1.80 (W1)	0.07-0.38 (W2)	0.05-0.73 (W2)
Cl^-	mg/l	2-392 (W21)	4-420 (W4)	2-390 (W21)	2-401 (W4)	0-381 (W4)	0-374 (W4)	0-404 (W4)
$SO_4^=$	mg/l	18-1,048 (W12)	6-1,546 (W12)	53-1,706 (W12)	0-1,293 (W13)	40-1,999 (W12)	0-1,439 (W9)	0-1,479 (W9)
Alkalinity (as $CaCO_3$)	mg/l	227-1,107 (W11)	150-1,120 (W26)	150-1,160 (W26)	210-940 (W11)	120-1,160 (W26)	210-1,300 (W16)	88-788 (W18)
Conductivity	umho	492-3,433 (W11)	425-3,450 (W4)	600-5,500 (W27)	460-3,900 (W12)	520-2,380 (W12)	420-3,200 (W12)	400-2,500
Ca	mg/l	58-534 (W12)	49-565 (W12)	34-549 (W12)	24-549 (W12)	52-395 (W9)	48-627 (W12)	38-405 (W9)
K	mg/l	0-19.1 (W21)	1-19 (W4)	1-19 (W21)	0-17 (W4; W21)	1-16 (W4; W21)	0-18 (W4)	0-19 (W4)
Na	mg/l	8-612 (W11)	13-620 (W26)	12-612 (W26)	5-630 (W26)	8-700 (W26)	7-630 (W26)	9-625 (W26)
Al	mg/l	0-4.9 (W11)	0-30 (W27)	0-10 (W23)	0-6.0 (W13)	0-7.0 (W23)	0-6.0 (W23)	0-3.0 (W23; (W24)
Cd	mg/l	0-0.02 (W11)	0-0.02 (W13)	0-0.03 (W13)	0-0.03 (W13)	0-0.02 (W11; W13)	0-0.02 (W4; (W13)	0
Cr	mg/l	0-0.01 (W12)	0-0.06 (W25)	0-0.04 (W25)	0-0.02 (W12; W13)	0	0	0-0.03 (W2; W6)
Cu	mg/l	0.01-0.09 (W13)	0-0.06 (W13)	0-0.12 (W22)	0-0.16 (W16)	0-0.16 (W16)	0-0.2 (W13)	0-0.22 (W12; W14)
Fe	mg/l	0.2-135 (W13)	0.1-135 (W9)	0.2-119 (W9)	0-123 (W13)	0.1-171 (W9)	0-107 (W7)	0.1-83.5 (W15)
Pb	mg/l	0-0.46 (W9)	0-0.40 (W13)	0-0.31 (W13)	0-0.76 (W13)	0-0.56 (W13)	0-0.12 (W12)	0-0.25 (W13)
Mg	mg/l	31-360 (W12)	0-410 (W12)	34-378 (W12)	28-472 (W12)	30-375 (W12)	32-430 (W12)	25-345 (W13)
Mn	mg/l	0.01-7.44 (W12)	0-8.05 (W12)	0-9.36 (W12)	0-7.63 (W12)	0.01-7.10 (W12)	0-8.95 (W12)	0.02-3.72 (W12)
Hg	mg/ml	0-0.4 (W13)	0.2-0.9 (W4)	0-4.4 (W4)	0-0.9 (W1)	0-0.5 (W13)	0-0.6 (W26)	0-0.6 (W1)
Ni	mg/l	0-0.1 (W13)	0-0.2 (W7)	0	0-0.2 (W13)	0	0	0-0.3 (W8)
Se	mg/l	--	--	0	0	0	0	0
Zn	mg/l	0-46.3 (W7)	0-49.6 (W13)	0-30 (W13)	0-61.5 (W13)	0-61.5 (W13)	0-11.8 (W7)	0-19.2 (W13)
Fecal Coliforms	1/100 ml	0	0-2 (W23)	0	0-60 (W7)	0-14 (W20)	0-2 (W8)	0-350 (W20)

(W) = well with maximum concentration.
( ) = well possibly affected by sludge application.

biochemical filter for the removal, conversion, and fixation of contaminants from sludges. Water quality at wells downstream from the sludge holding basins cannot be differentiated from the quality of background wells.

Wells W4, W8, W10, and W20 indicate a trend of nitrite and nitrate nitrogen build-up. Concentrations at background Wells W4 and W20 are projected to exceed the 10 mg/l drinking water standard for nitrite and nitrate nitrogen by 1988 and 1993, respectively. Well W8, possibly influenced by sludge application, could exceed the drinking water standard for nitrite and nitrate nitrogen by 1977. The existing nitrite and nitrate nitrogen level in Well W10 presently violates the U.S. Public Health Service standard for drinking water, and is deteriorating at a rate of 0.5 mg/l per month. In the absence of complete groundwater flow data, sources of contamination of Wells W8 and W10 cannot be identified. Also, water quality data is insufficient for a long-range projection of groundwater quality.

3. Mitigation of Adverse Effects

Groundwater quality monitoring and analysis should be continued to detect possible contamination from the project. Whenever exceptionally poor groundwater quality is documented, responsible sources of contamination should be identified and effective control measures implemented. Injection of tracers such as chemical isotopes into upstream wells, and subsequent tracer detection in other wells will help to reveal the direction and velocity of groundwater movement around the project area. This knowledge would aid the identification of contaminant sources, especially in distinguishing project sources from strip-mine sources of pollution.

G. POTENTIAL SOIL CONTAMINATION

Potential soil contamination from the application of stabilized municipal sludge has been a topic of public concern. The problems are primarily focused upon the possible build-up of trace metals or toxic materials in the soil, particularly in the root zone. The soil composition and possible soil contamination problems are discussed below. Potential impacts and desirable safeguards are considered.

1. Chemical Concentrations at Soil Boring Sites

Over 52 soil borings were made to bedrock to determine the physical and chemical characteristics of soils and rocks. Physical soil characteristics, such as permeability, were used to examine potential groundwater contamination from the project.

The chemical composition of both mining spoils and place land is summarized in Table VII-14. Included are the mean, maximum, and minimum values of exchangeable calcium, organic carbon, and hydrochloric acid-extractable metals such as Al, Cd, Cr, Cu, Pb, Mn, Ni, and Zn. In general, the spoil material and place land have approximately equal concentrations. The mining spoil contains significantly higher levels of cadmium and copper. This is believed to be the result of past strip-mining activities. The spoil materials contain more exchangeable calcium but less organic carbon than place land. The higher organic carbon content of the place land indicates that it is more fertile.

The proposed second set of soil borings to follow the first 5 years of project operation has not been made as yet. Therefore, no comparative study can be done to determine any changes in soil structure or chemistry.

2. Potential Impacts

Due to the paucity of data, impacts on the soil quality resulting from the project cannot be defined. However, some speculated impacts

Table 14. Metals, Exchangeable Calcium, and Organic Content of Spoil Material and Place Lands in Fulton County Prior to the Application of Digested Sludge (MSDGC, Spring 1972)

SITE SAMPLED	0.1 N HCl EXTRACTABLE ✡								EXCH. Ca	ORGANIC CARBON
	Mn	Zn	Cu	Cd	Cr	Ni	Pb	Al		
	µg/g OF OVEN DRY SOIL								%	%
SPOILS										
MEAN	154	31.7	4.79	0.2	1.22	6.7	3.52	509	0.83	0.61
MINIMUM	79	11.1	1.90	0	0	3.2	0	384	0.63	0.24
MAXIMUM	208	69.4	19.1	1.36	3.40	10.0	8.50	620	1.12	1.56
PLACE LAND										
MEAN	146.1	31.4	2.62	0.08	1.23	7.5	4.55	540	0.36	1.64
MINIMUM	92.0	10.3	1.48	0	0.30	3.2	2.23	317	0.20	0.92
MAXIMUM	258.6	68.7	3.73	0.68	3.17	12.7	7.94	741	0.72	4.55

✡ THREE SUCCESSIVE 5 MINUTE EXTRACTIONS OF 1.5 GRAMS SOIL WITH 15 MILLILITERS OF ACID.

are discussed below. The purpose of this discussion is to provide an orientation for the analyses of the follow-up soil borings, so that complete delineation and assessment of possible problems can be achieved.

It is suspected that high concentrations of soluble salts in the sludge may affect soil chemistry and plant growth, possibly causing excessive plant uptake of toxic materials or trace metals. Allison (1964) stated that salts directly affect plant growth by increasing the osmotic pressure of the soil solution, altering mineral nutrition, and causing toxic accumulations of specific ions in the plants.

The trace elements in municipal wastes may occur largely in association with complex organic polyanions. This interaction between heavy metals and humic, polymeric substances in the sludge and soil may have a profound effect upon the mobility and toxicity of metal ions when sewage sludge is applied to agricultural soils. The reactions of metal ions in the soil solution include solution, oxidation, reduction, precipitation, adsorption, absorption, and complexation, all of which may result in a build-up of trace metals. In terms of complexation, the University of Illinois has developed a mathematical model based on Schubert's ion exchange equilibrium technique. The model can measure stability constants of metal-polyelectrolyte complexes naturally occurring in soils and digested sewage sludge, and may be useful in predicting the fate of heavy metals applied as constituents of stabilized municipal sludges (Hinesly _et al._, 1971).

A review of literature and studies on the build-up of trace elements in soils receiving sewage sludge is provided in Chapter IX. The subsequent effects of trace element build-up in soil on crop growth and human health via biomagnification in food chains are also discussed.

3. Mitigation of Adverse Effects

The most important task in delineating possible degradation of soil quality is to perform a second series of soil test borings and analyze soil characteristics, especially in the root zone. Physical and chemical quality of soils with and without sludge application should be defined. A comparison between properties of background soils and soils receiving various amounts of sludge should detect any build-up of trace metals or toxic materials.

Lysimeter studies in the laboratory would help to understand the soil chemistry and reactions controlling the fixation and mobilization of trace elements. Results of this type of study can be used to estimate the capacity of soil to hold trace elements without significant effects on plant growth and groundwater quality. Once the soil capacity for handling trace elements is established, the upper limit for sludge application can be estimated and enforced.

H. POTENTIAL NOISE PROBLEMS

Unwanted sound, referred to as noise, may be generated by most mechanical equipment, including the pumps, tractors, and sludge-sprayers at the project site. Noise can have impacts on people ranging from simple annoyance to psychological and physiological stress. Such reactions include increased irritability, loss of concentration, nervous tension, impaired aptitude, and loss of sleep. The extent of the impact depends primarily on the loudness, pitch, intermittency, and familiarity of the noise reaching sensitive human receivers. Noise measurement and attenuation, project noise sources and levels, potential noise impact and mitigative measures are considered in this section.

1. Noise Generation at the Project Site

Noise levels are typically measured in decibels in the "A" scale (dBA). The scale emphasizes a certain set of frequencies to which the human ear is most sensitive. Examples of common indoor and outdoor noise levels are listed in Figure VII-22.

Noise can be attentuated before reaching sensitive human receivers. Distance, vegetation, and topography, including hills and walls, can reduce noise levels significantly. For example, a 5-foot wall has been shown to reduce highway noise by five dBA (Sexton, 1969). Vegetation must be quite dense to attenuate noise. In an area of dense evergreen woods with a visibility of 70 to 100 feet, the attenuation of sound is approximately 18 dBA per 1,000 feet. Trees with trunks 6 to 8 feet high and spaced about 10 feet apart provide no attenuation (Embleton and Thiessen, 1962). Planting vegetation to improve the aesthetic appearance of the noise-generating site has been shown to reduce local sensitivity to noise without actually reducing the noise levels (Sexton, 1969).

The project is located in a remote rural area. The closest communities are Canton, Cuba, St. Davis, and Bryant, with a combined population of less than 15,000. The ambient noise level is similar to that of typical rural areas and is estimated to be not more than 45 dBA 90% of the time, which is designated the 10-percentile noise level.

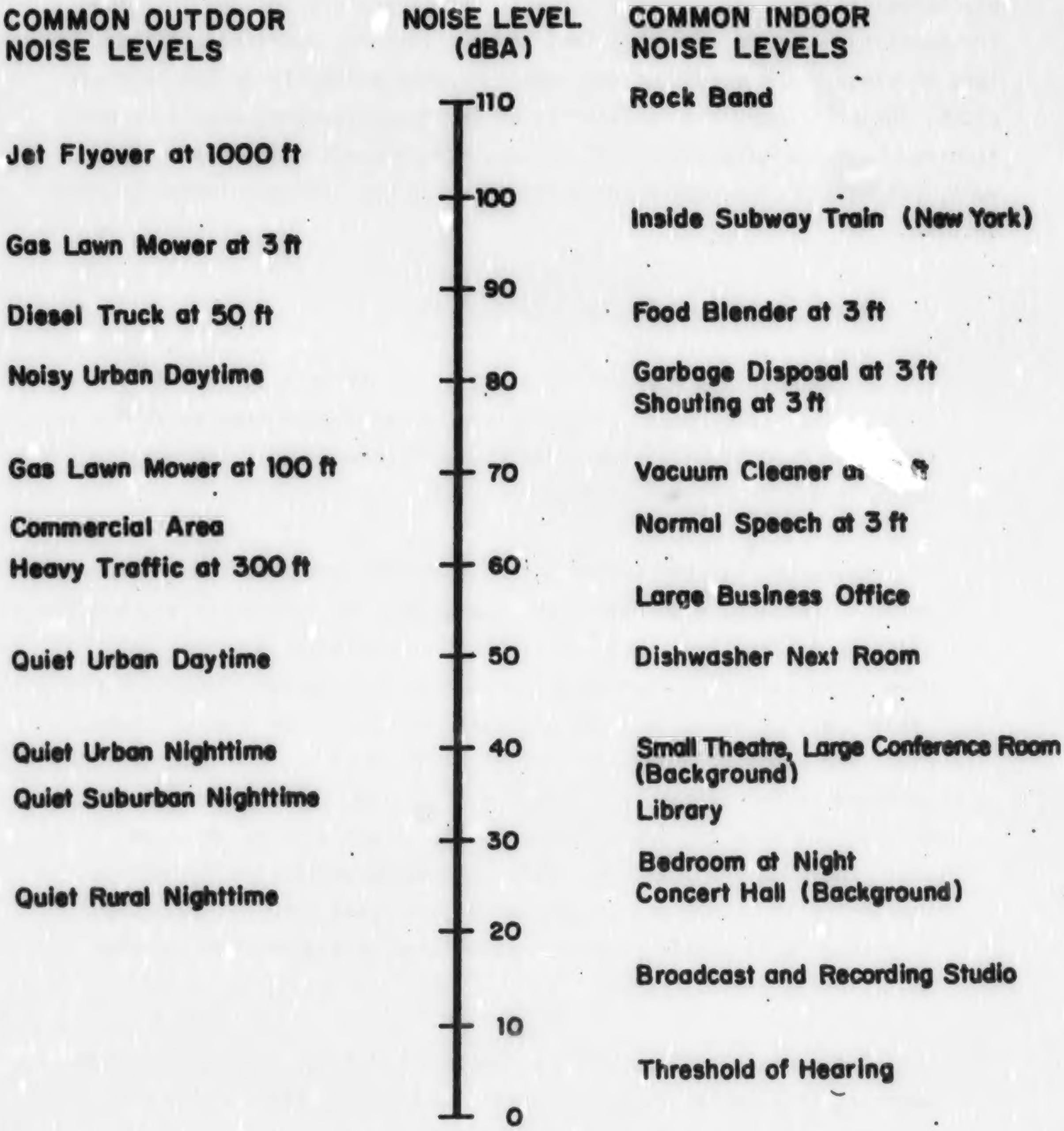


Figure VII-22. Common Indoor and Outdoor Noise Levels
(U.S. Department of Transportation, 1973)

Sources of noise in the environment of the project include tractors on the adjacent farms and occasional motor vehicles on highways and local roads. Because the traffic is light, these sources do not contribute significantly to the ambient or background noise level. Sources of noise related to the project include pumps, tractors, and sludge sprayers. Three pumping or sludge distribution stations are located within project property, and one booster station is situated at the Liverpool dock. The pumping stations on the project site are at least one mile from the nearest farmstead. However, the booster station at the Liverpool dock and barge pumps are within a half-mile radius of Liverpool, which had a population of 218 in 1970 (U.S. Bureau of Census, 1972). Tractors, trucks, and sludge sprayers are mobile noise sources. This equipment will generate noise detected by sensitive receptors only when in operation near the boundary of project property.

The typical ranges of sound pressure levels from pumps and vehicles are shown in Figures VII-23 and VII-24. As a conservative estimate, the noise level for an unenclosed pump is about 95 dBA 3 feet away from the pump, and about 80 dBA 25 feet from a tractor and sprayer. The noise levels at different distances from these sources are derived from the dissipation law of sound pressure and are shown below in Table VII-15. These values were calculated assuming the absence of sound barriers such as buildings, dense vegetation, and terrain with high relief.

Table VII-15. Noise Level in dBA of Various Noise Sources as a Function of Distance (Enviro Control, Inc., 1976)

	Distance from Noise Source						
Noise Source	3 ft.	25 ft.	100 ft.	800 ft.	1,600 ft.	3,200 ft.	5,280 ft.
Pump without Enclosure	95	86	80	71	68	64	63
Tractor and Sprayer	--	80	74	65	62	59	57

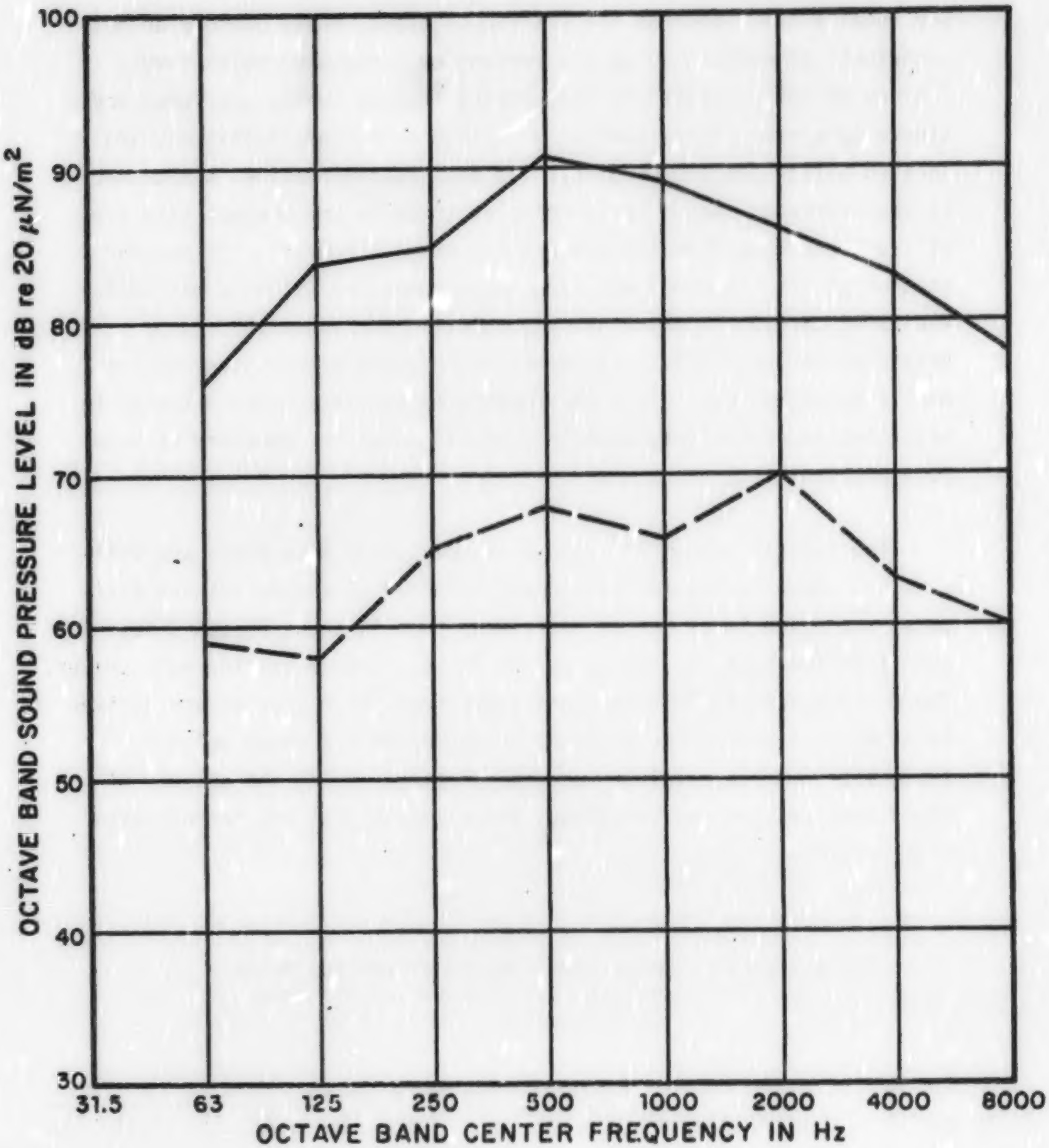


Figure VII-23. Range of Sound Pressure Levels from Pumps (Measured at 3 ft.) (Curves Represent Upper and Lower Boundaries of Range), (U.S. EPA, 1971a).

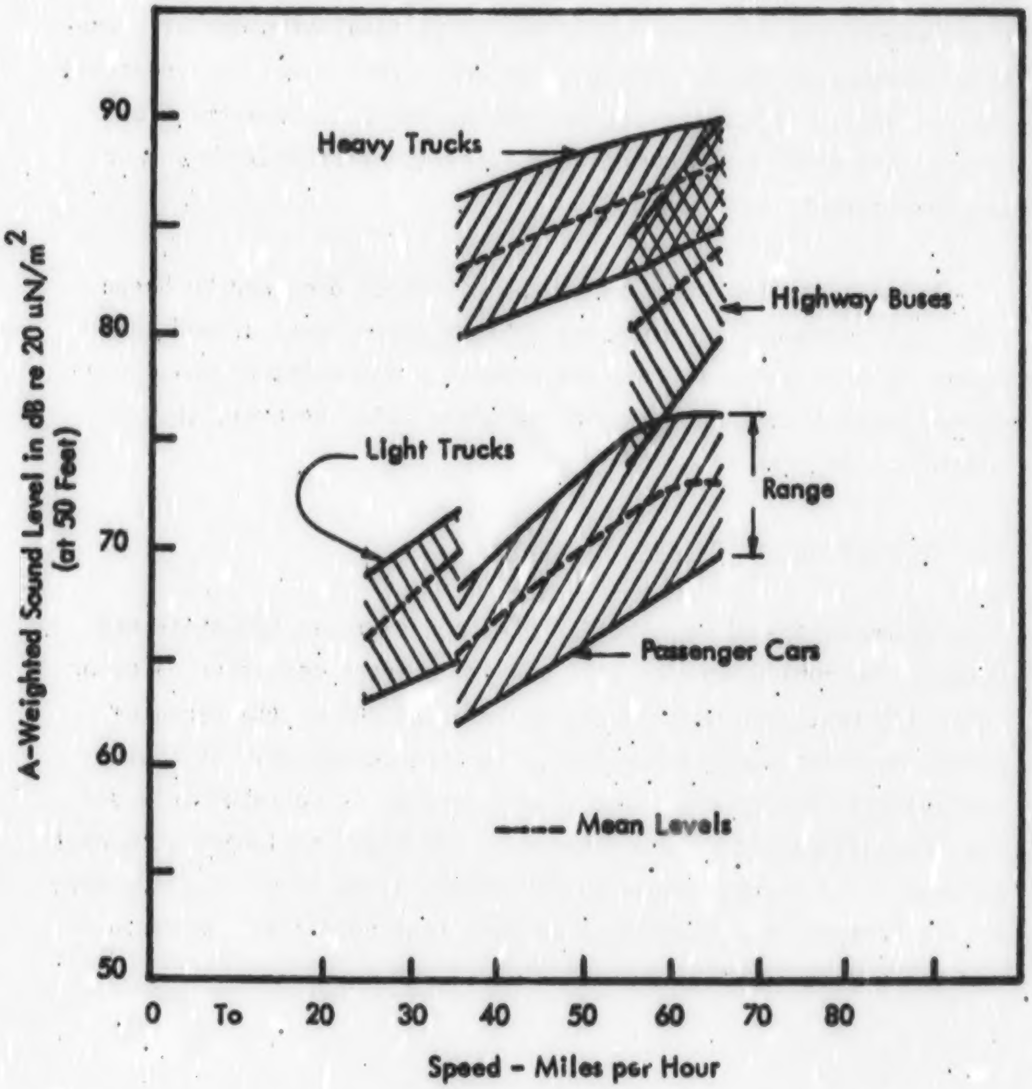


Figure VII-24. Single Vehicle Noise Output as a Function of Vehicle Speed (U.S. EPA, 1971b).

2. Potential Impacts

Noise impacts from the pumping station are minimized because of a one-mile buffer distance between the station and the closest farm families. Considering further dissipation of noise by buildings, vegetation and topography, the noise level of pumps at a one-mile distance should be less than 60 dBA. This level is acceptable for residential areas, as recommended by the U.S. Department of Housing and Urban Development (U.S. Department of Housing and Urban Development, 1971 and 1972).

Noise generated by pumps at the Liverpool dock and by barge pumps will somewhat increase the ambient noise level around the community of Liverpool. Impacts from this intermittent noise cannot be quantified in the absence of noise data; however, they should not be severe.

3. Mitigation of Adverse Effects

Assuming the minimum buffer distance that can be maintained between the mobile sprayer unit and the nearest sensitive receptor to be 400 feet, the noise level would be 68 dBA at the receptor during spraying operation. This situation occurs only at Fields #31 and #34 through #37. The sludge sprayer is operated only during the daytime and seldom remains at one location longer than half an hour. The average upper 10 percentile noise level (L_{10}) of the mobile sprayer is estimated to be less than 60 dBA at the receptor and is compatible with residential land use.

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VIII. DIRECT HEALTH EFFECTS OF THE PROJECT

Sludge contains toxic substances such as heavy metals and also may contain human and animal pathogens and parasites. If humans or animals are exposed to these hazardous components in sufficient quantities, adverse health effects could result. There are two routes by which these components could be transferred from the sludge to the receptor: the direct route, as in the inhalation of airborne particles; and the indirect route, as in the uptake of heavy metals by plants consumed by animals or man. Indirect health effects are discussed in the next chapter. This chapter deals with the direct health effects, in terms of theoretical considerations and estimated potential health hazards from airborne pathogens and toxic substances. The chapter concludes with recommended measures to prevent or mitigate direct health hazards.

A. THEORETICAL CONSIDERATIONS IN ASSESSING DIRECT HEALTH EFFECTS OF SLUDGE AEROSOLS

Among all methods of sludge application, pressurized spraying offers the greatest potential for direct transfer of hazardous components to humans or animals. Inhalation presents an opportunity for protracted and repetitive exposure and does not necessarily stimulate preventive action by those at risk. In contrast, entry through a wound or by hand-to-mouth transfer occurs only occasionally and is likely to be consciously avoided. The largest source of inhalable material per unit of sludge applied is pressurized spraying. Lightly pressurized sprinkling or other irrigation releases a lesser amount, and other methods can be classified as negligible sources.

1. Pressurized Spraying

This section examines the phenomenon of aerosol formation, the origin and survival of pathogens in sludge, and the presence of toxic substances.

a. Aerosolization of sludge particles - Any spraying operation is a potential source of aerosol particles, even if carefully designed and operated to deposit large droplets in the immediate vicinity. The separation of a liquid jet into drops is accompanied by the generation of very small "satellite" droplets when the liquid thread connecting two drops is broken. A film of liquid similarly separates into large and small drops. These aqueous droplets evaporate rapidly until their vapor pressure equilibrates with the partial pressure of water vapor in the atmosphere. Suspended and dissolved substances, as are found in sludge, leave a residual particle containing some water retained by physical or chemical processes.

The size of the equilibrated particle depends on the non-volatile residue. If the bulk density of this is close to one, size follows directly from the wet droplet size and composition. For example, a 15- μ-diameter droplet containing 4% solids will decrease in volume to 1/25, and the diameter will decrease by $1/\sqrt[3]{25}$ or approximately 1/3, becoming about 5 μ. This calculation can be used if engineering data on a spraying system is available, and will determine the amount of sprayed material that will form particles small enough to remain airborne, and hence the amount in readily inhalable form. In the present case, there are neither direct measurements of airborne quantities nor the data necessary for calculation. This analysis must therefore rely upon intelligent estimates and data from systems elsewhere.

The total non-volatile content of the sludge influences the particle size. Analysis of the sludge determines the amount of hazardous material in each particle. It may be noted that bacteria, which are sizeable compared with the droplets (of the order of 1-μ diameter), will not inhabit all droplets; this is especially true for larger amebic cysts, helminth eggs, and so forth. Dissolved substances, in contrast, are present in all particles.

From the point of view of mitigating hazards, it should be noted that spraying can be designed to minimize, but not to eliminate, aerosol formation.

b. Bacterial and viral pathogens -

> Before treatment, domestic wastewater usually contains the complete spectrum of pathogenic microorganisms discharged by the community... (Viraraghavan [1973], quoting Greenberg and Dean [1958], Rudolfs *et al*. [1950a,1950b]).
>
> Crude sewage contains all the [types of] agents causing infectious disease in man -- bacteria, viruses, protozoa, intestinal parasites excreted through the intestinal tract. Of these, organisms of the *Salmonella* group, which are widely distributed in man and animals, are by far the most common in developed countries. (McCoy, 1971)

Although greatly reduced in number, many pathogens survive wastewater treatment, including salmonellas, *Mycobacterium tuberculosis*, and many enteroviruses (viruses of the gastrointestinal tract). These may even survive chlorination, and it has been shown that the absence of coliforms does not necessarily indicate virus inactivation (Allen *et al*., 1949; Sorber, 1973; Kruze *et al*., 1970; D'Itri *et al*., u/d). The microbial population of sludge is greatly reduced by holding for a few weeks, but is not eliminated completely.

Pathogens may be present in sludge even after months of lagooning. A major factor influencing their presence and quantity is the community's discharges into the system, which may be expected to be highly variable. Sources are human and animal and they include slaughter houses, the meat products industry, poultry and egg processing plants, tanneries, and many others (McCoy, 1971). It is evident that the nature and concentrations of pathogens entering and potentially surviving treatment must vary widely from place to place and time to time. Evidence from places other than Fulton County are therefore of little predictive value, and samples taken in Fulton County at one point in time will not necessarily be valid for other times. For example, midday counts of

E. coli (all x 10^6/ml) in a certain sewage effluent were 5.5 in January 1970 and 0.18 in September 1970, and midnight counts were 0.3 in both months (McCoy, 1971). Futhermore, E. coli are the overwhelmingly dominant bacterial species in domestic waste; diseases of seasonal and epidemic character would show much wider fluctuations.

c. Heavy metals and other toxic substances - Treatment plants handling a substantial proportion of industrial waste are liable to have a considerable burden of toxic substances in the sludge. Thorne, Hinesly and Jones (1975) report the following figures:

Table VIII-1. Composition of Fresh, Heated, Anaerobically Digested Sewage Sludge (Thorne *et al*., 1975)

	Dry Sludge Basis		
	Concentration Range (ppm)	Typical Concentration (ppm)	Typical Amount (lb/ton)
Cadmium (Cd)	3 to 3,000	150	0.3
Chromium (Cr)	50 to 30,000	3,000	trace
Lead (P)	100 to 10,000	1,000	6
Mercury (Hg)	1 to 100	3	2
Nickel (Ni)	25 to 8,000	400	0.8

For comparison, data available from Fulton County reveal an average of about 450 ppm for cadmium, and a maximum concentration of 1,125 ppm.

It must be emphasized that the input rate for such materials at the treatment plant is likely to vary widely, even during stable conditions of industrial production with discharges occurring, for example, at one step in a batch process or during periodic cleansing. When processes change or new processes are introduced, further variations in the effluent may be expected. Consequently, a few grab samples widely separated in time may give a highly misleading indication of average concentrations.

2. Variables of Airborne Transmission

The purpose of this section is to identify and discuss the variables other than those associated with the sludge itself, which influence the extent of any potential hazard.

a. Variables at the source - The amount of material exposed to a downwind receptor is directly proportional to the rate and duration of emission at the source, provided that all other conditions remain constant. It depends, therefore, on the amount of sludge sprayed and the proportion converted into windborne particles. Data is available on the rate of application, but the proportion aerosolized must be determined by guesswork. From knowledge of similar operations, it would appear that 1% is a reasonable estimate.

No great significance is attached to the size distribution of the airborne particles. As will be pointed out later, this is not an important variable in most cases. The information necessary to make use of this variable is not available.

Linear dimensions of the source are important. If a continuous point source is traversing an area, such as a mobile sludge sprayer in a field, the total amount arriving at the receptor will depend on emissions from all points in the area. Calculation of dosage therefore involves the linear dimensions of the area traversed by the spraying device.

b. Variables in transit - If airborne particles are released at a given rate, the downwind concentration will vary in response to three influences. The concentration is inversely proportional to windspeed, because this determines the downwind particle spread. The particles are also spread out vertically and across the wind by turbulent mixing of the air. The third factor is deposition. For example, a 50-μ particle of unit density has a settling rate of about 10 cm/sec and will fall through 1 meter of still air in 10 seconds. However, some particles will remain airborne much longer in a turbulent atmosphere.

Another form of physical depletion is from impaction on surfaces. This is not a significant factor in the present context. For this type of deposition to occur, particles must be relatively large, windspeed must be high, or the obstacle must be very narrow; otherwise, the particles simply slip by the obstacle in the streamlines. Therefore, vegetative barriers cannot be expected to effect any substantial depletion in particles of respirable size.

Pathogens are subject to another form of depletion which can be extensive. Most pathogens are affected by desiccation and exposure to the atmosphere, and are also highly susceptible to sunlight or even diffuse daylight. A pathogenic bacterium which would have survived for weeks in aqueous suspension may be killed in seconds if transferred to an airborne droplet a few microns in diameter and exposed to daylight. It must be emphasized, however, that this response is extremely variable. Some live microorganisms are found in the upper atmosphere, and others cannot survive brief desiccation in the dark. The composition of the suspending medium is one of the many controlling variables. Other sludge ingredients may have a large retarding or accelerating effect on loss of viability (Webb, 1959, 1960a, 1960b).

c. Variables at the receptor - A breathing human is an active receptor (as opposed to a passive obstacle), "sampling" the air and trapping particles of different sizes in various parts of the respiratory tract. The rate of "sampling" depends upon the degree of activity and can vary by one order of magnitude or more. An average figure of 20 liters per minute,corresponding to light activity, will be used in this analysis. Efficiency of retention varies from 100% for larger particles to about 25% for those least retained. However, most of the total mass of airborne material will be in particles for which 100% retention is an acceptable approximation.

Account will not be taken of the effect of particle size on the infectivity of some microorganisms. It is certainly true that the number of microorganisms required to infect exposed subjects will vary greatly with particle size. Experiments performed with bacterial agents in animals have shown that the infective dose is much less for 1-μ than 10-μ particles, the transition occurring at about 5 μ and corresponding with a transition from deposition in the lower to the upper respiratory tract (Harper and Morton, 1953; Druett et al., 1953). Particles less than 5 μ in diameter are frequently spoken of as being in the "respirable" size range, and many recent papers, including several on sewage aerosol hazards, are written as though larger particles were not hazardous. However, there is evidence that the difference is small in some cases (e.g., for Pasteurella pestis in the rhesus monkey), and it may be supposed that enteroviruses, impacted in the upper respiratory tract and subsequently swallowed, can infect via the gastrointestinal tract. Furthermore, we are also concerned with toxic substances for which the portal of entry may bear little significance.

3. Calculation of Downwind Sludge Particle Concentration

The portion of the sprayed sludge which becomes airborne and available for inhalation, the downwind concentration, and the amount retained in the respiratory system are all independent of the presence of pathogens or toxic substances. The proportion of potentially hazardous components is too small to affect the physical variables controlling the characteristics of the system. Consequently, the most convenient approach is to calculate the exposure of downwind receptors to airborne sludge particles, and convert this to intake of hazardous substance by using the known or hypothesized concentration in the sludge.

Another step that is taken to produce a general model applicable to a range of conditions is to deal with a single day's application by one spraying array, using typical dimensions for the operation. These calculations can be easily used to estimate the effect of a day's operation with different dimensions, and the cumulative effect of several operations.

a. Operational characteristics - A typical day's operation was chosen to be represented by the following conditions:

- Application area = 24 acres or 116,160 square yards (assumed to be a square with 341 yd. or 312 m side)
- Application rate (dry basis) = 54 dry tons total or 2.25 tons per acre
- Duration of application = 12 hours
- Sludge solids composition = 4.5%.

These dimensions are based on information obtained from the Prairie Plan management, stating that sludge is sprayed at a rate of 2 acres per hour to a depth of 1/2 inch for a period of 8 to 16 hours per day, depending upon length of the day. On the basis of this information, the total dry tonnages of sludge applied in one day are presented in the following table.

Table VIII-2. Amount of Sludge Applied as a Function of Spraying Time (assuming 4.5% solids)

Hours per day	Acres per day	Dry tons
8	16	36
10	20	45
12	24	54
16	32	72

It is further assumed that 1% of the total sludge sprayed becomes airborne, the spray trajectory peaks at 45 ft or about 14 m, and a 12-hour daily application period is average. The percentage airborne is based only on general knowledge of aerosol formation in large-flow-rate jets. The spray trajectory assumes a discharge elevation of 45° and throw radius of 100 to 150 ft (Prairie Plan staff). The meteorological conditions assumed for the purpose of this study are a windspeed of 5 m/sec and Stability Class B, representing most probable conditions, and a windspeed of 1 m/sec and Stability Class D, representing worst case conditions. These meteorological conditions are based on an estimate of average local daytime conditions on days suitable for sludge spraying during the irrigation season. It was felt that a more thorough analysis of climatological data would not justify the considerable effort, in view of the larger uncertainties stemming from variables of airborne concentration of the hazardous material and of receptor response.

b. Model approach - Receptor response is assumed to be proportional to cumulative exposure, as is common for pathogens and chronic poisons. The source is regarded as a uniform area source, the area being the acreage sprayed in one day. This is assumed to be a square with a side perpendicular to the wind, and the area source is conveniently approximated as a crosswind line through the center of the square.

Lateral dispersion is treated by the virtual point source method. An upwind point is computed, from which emitted particles would give a cloud width equal to the crosswind line in the given stability conditions. Downwind diffusion is then calculated as though the source were at the virtual point. Similarly, an upwind point (or line) is computed to give a cloud height equal to the actual height from the top of the spray trajectory to the ground.

Receptors are placed at various distances downwind from the downwind side of the square, to approximate several actual conditions:

- 100 m -- operator or close onlooker
- 500 m -- nearest uninvolved bystander
- 1000 m -- nearest resident population cluster.

c. Model calculations - The diffusion equation used is:

$$X = \frac{Q}{\pi \sigma_y \sigma_z u}$$

where

X = concentration (g/m^3)
Q = source emission strength (g/sec)
π = 3.14
σ_y = crosswind standard deviation
σ_z = vertical standard deviation
u = windspeed (m/sec)

To calculate the source emission strength (Q), the total dry weight of sludge applied is converted to grams:

$$54 \text{ tons} \times 2{,}240 \text{ lbs/long ton} \times 454 \text{ g/lb} = 5.5 \times 10^6 \text{ g}$$

The duration of the sludge application period is then converted to seconds:

$$12 \text{ hrs} \times 3{,}600 \text{ sec/hr} = 4.32 \times 10^4 \text{ sec}$$

Source emission strength is then calculated using the total dry weight and period of duration:

$$5.5 \times 10^6 \div 4.32 \times 10^4 = 1.27 \times 10^2 \text{ g/sec}$$

The area source is approximated as a 312-meter crosswind centerline; its standard deviation is estimated to be 73 meters [312 ÷ 4.3] (Turner, 1969). For Stability Class B, representing average meteorological conditions at the project site, this corresponds to an upwind point source at 430 meters, or 1,060 meters for Stability Class D which represents the worst case. Total distance is calculated by adding the receptor distance to the upwind source distance. Table VIII-3 below presents values of the crosswind standard deviations (σ_y) for Stability Classes B and D and for three receptor distances.

Table VIII-3. Values of Crosswind Standard Deviation (σ_y)

	Stability B		Stability D	
Receptor Distance (m)	Total Distance,	σ_y	Total Distance,	σ_y
256	686	110	1316	88
656	1086	170	1716	112
1156	1586	235	2216	142

The upper boundary of the source has been estimated at 14 m above ground. Assuming this to represent two standard deviations, we have a σ_{Z_0} value of 7 m. For stability B, this corresponds to an upwind ground level source at 70 m and for stability D, 160 m. Total distance is calculated by adding the receptor distance to the upwind ground level source distance. Table VIII-4 presents values of the vertical standard deviation (σ_z).

Table VIII-4 Values of Vertical Standard Deviations (σ_z)

	Stability B		Stability D	
Receptor Distance (m)	Total Distance,	σ_z	Total Distance,	σ_z
256	326	33	416	16
656	726	75	816	28
1156	1226	135	1316	38

Now the value of X for average and worst case conditions can be calculated as follows:

$$X = \frac{Q}{\pi\sigma_y\sigma_z u} = \frac{Q}{F}$$

Table VIII-5. Values of Sludge Aerosol Concentrations (X)

Stability B (Windspeed = 5 m/sec)

Receptor Distance (m)	π	σ_y	σ_z	u	F	Q/F (g/m^3)
256	3.14	110	33	5	5.7×10^4	2.2×10^{-3}
656	3.14	170	75	5	2.0×10^5	6.4×10^{-4}
1156	3.14	235	135	5	5.0×10^5	2.5×10^{-4}

Stability D (Windspeed = 1 m/sec)

Receptor Distance (m)	π	σ_y	σ_z	u	F	Q/F (g/m^3)
256	3.14	88	16	1	4.4×10^3	2.9×10^{-2}
656	3.14	112	28	1	9.8×10^3	1.3×10^{-2}
1156	3.14	142	38	1	1.7×10^4	7.5×10^{-3}

d. Daily respiratory intake - Assuming that the receptor is an adult male engaged in light activity throughout the spraying period, the respiratory intake rate is equal to 20 liters per minute for a duration of 12 hours. The intake would, of course, be proportionately less for a shorter exposure time. The total inhaled volume is equal to:

$$20 \text{ liters/min} \times 12 \text{ hrs} \times 60 \text{ min/hr} \times 10^{-3} \text{ m}^3/\text{l} = 14.4 \text{ m}^3$$

By multiplying the total volume inhaled by the aerosol concentrations (x) calculated above, a daily respiratory intake of sludge can be determined.

Table VIII-6. Calculated Respiratory Intake of Sludge Particles for One Day of Spraying

Receptor distance (m)	Stability B (wind 5 m/sec)	Stability D (wind 1 m/sec)
256	3.2×10^{-2}	4.2×10^{-1}
656	9.2×10^{-3}	1.9×10^{-1}
1156	3.6×10^{-3}	1.1×10^{-1}

This table also shows the daily intake in micrograms of a substance present in the sludge at 1 ppm (dry weight), and can be used to calculate the intake of a substance present at any other concentration. For example, if cadmium is present at 200 ppm, the 256-m receptor, in stability D, will take in:

$$4.2 \times 10^{-1} \times 2 \times 10^{2} = 84\ \mu g.$$

The emphasis of attention in Fulton County and elsewhere has been on pathogenic hazards by direct and indirect routes and toxic substance hazards by indirect routes only. It is felt that the direct route has been unduly neglected. The ensuing calculations show that airborne spray may also impose toxic risks.

Analysis of the sludge applied in Fulton County is presented in Table VIII-7. Multiplying the sludge respiratory intake by the appropriate concentration of a substance gives the estimated respiratory intake of that substance.

Table VIII-7. Analysis of Liquid Sludge (ppm dry wt)

Date	Total Solids (%)	Concentrations (mg/l)					
		Cd	Cr	Cu	Pb	Hg	Zn
June 1974	4.10	8.8	104	59.7	32	173	125
July 1974	4.16	11.9	154	71.3	37	226	168
Aug. 1974	4.24	13.5	131	75.9	37	203	168
Sept. 1974	3.88	11.4	110	60.6	31	197	150
Oct. 1974	4.23	13.8	125	69.5	27	141	166
Avg.	4.12	11.9	125	67.4	33	188	155
Avg. (ppm, dry wt. basis)	--	289	3040	1640	800	4570	3770

Table VIII-8. Calculated Respiratory Intake (ug)

Metal *	Receptor distance (m)	Stability B (5 m/sec)	Stability D (1 m/sec)
Cd [70 µg]	256	9.2	121
	656	2.7	55
	1156	1.0	32
Cr	256	97	1277
	656	28	578
	1156	11	334
Cu	256	52	689
	656	15	312
	1156	6	181
Pb [430 µg]	256	26	336
	656	7	152
	1156	3	88
Hg [43 µg]	256	146	1919
	656	42	868
	1156	16	503
Zn	256	121	1584
	656	35	716
	1156	14	415

*Bracketed numerals represent WHO recommended maximum daily intake

In comparing the calculated estimates of respiratory intake with WHO-recommended maximum daily intakes, it must be remembered that the WHO figures are for continued daily intake. The figures for cadmium (Cd), for example, show intakes under "worst case" conditions which are similar to the WHO limit, but subjects are unlikely to be exposed to spray for more than a few days per year. A possible exception is the operators who might experience a substantial aggregate of exposure if they work consecutively in many fields. The figures for mercury (Hg), in particular, suggest that significant doses could be received. It may be supposed, however, that protracted exposure downwind is unlikely to occur.

Calculations such as these made for pathogens instead of heavy metals would have to account for the proportion of bacteria or virus particles that remain infectious after spraying and downwind travel. This amount could be very large and would vary tremendously under different environmental conditions. Furthermore, airborne survival is quite unpredictable except for highly robust species.

B. POTENTIAL DIRECT HEALTH HAZARD OF AIRBORNE PATHOGENS AND TOXIC SUBSTANCES

The purposes in this section are to review the likelihood of airborne survival of pathogens and their dose effects, handicaps due to data shortcomings, and implications of air contamination for human and animal health based on studies in the literature.

1. Areas of Variability and Uncertainty

The nature and concentration of pathogens in the sludge is an extremely variable and uncertain area. Well water, streamwater, and soil sampling programs do not serve as useful indicators of pathogen concentrations in the sludge at the time of irrigation, because surface exposure and percolation through the soil are extremely effective cleansing processes. Pathogen die-off during sludge storage in the holding basins in another important variable, depending on storage time.

a. Airborne pathogen survival - The second area of variation is in airborne survival. Most microorganisms, especially pathogens, lose viability when sprayed, mainly because of the "drying" process of equilibration with the atmosphere, and sensitive organisms may be sterilized. However, there are some which are not affected and continue to survive indefinitely in the dark; spores of Bacillus anthracis are an example. The rate of decay is influenced by temperature and humidity, being accelerated by higher temperature and responding variably to humidity. For example, the polio virus survives best at high humidity, and vaccinia, influenza and Venezuelan equine encephalomyelitis viruses at low humidity (Harper, 1961). The survival of vegetative bacteria five munutes after spraying demonstrate the variability experienced with different humidities and bacterial species (see following Table VIII-9).

Table VIII-9. Five-Minute Survival (%) at Different Humidities (Morton, 1962)

	Relative Humidity		
	85-87%	50%	20%
Brucella suis	91	78	--
Bact. tularense	42	26	1.9

These experiments were performed at 45° to 54°F in the dark; higher temperatures show similar effects, and sunlight is extremely destructive for bacteria and viruses. Responses to temperature, humidity and light are strongly modified by substances accompanying the microorganism in the airborne particle, but this effect is unpredictable. Other material in a sludge aerosol will probably favor pathogen survival, but laboratory or field data for aerosols formed elsewhere from different aqueous media cannot be applied to Fulton County with confidence.

b. Receptor dose effect - A third area of uncertainty is dose-effect relations. The number of inhaled organisms required for infection of humans is very difficult to determine. Similar information concerning toxic substances is more readily available because animal experiments in that area can be extrapolated more reliably. Quantitative estimates of accidental human exposure to toxic substances are easier to make, and direct human experimentation with low doses is often acceptable. In contrast, species-to-species extrapolation is far less reliable for pathogens, quantitative evidence is seldom available for accidental infections, and human experiment is usually barred. There are a few sound data concerning human infection by the respiratory mite, such as for Q fever and tularemia, but no data are available concerning likely pathogenic hazards of sewage sludge. A further complication is that operators and local inhabitants, those most at risk, may be subject to repeated exposures of subinfective live pathogens or large numbers of dead pathogens. Such exposures are recognized ways for building immunity and might affect the sensitivity of the local population.

2. Absence of Appropriate Data

There are several reasons why the pathogenic hazard is very difficult to predict:

- Occasional samples taken may be quite unrepresentative
- Pathogen content of the sludge as sprayed is unknown
- If pathogen content were known, airborne survival would be quite unpredictable
- If air samples were available for estimating the respira tory intake, the effect on exposed humans could not be predicted.

Any evaluation of direct health hazards at Fulton County must therefore be a matter of judgment based on indirect evidence. An objective evaluation would be possible if certain observations were made. On the other hand, if spray operations are drastically reduced as presently planned, there is little need for such observations.

The direct evidence concerning the sludge as sprayed does not offer more than a broad estimate of chemical composition and an indication, based on lagoon sampling, of a bacterial content that is much lower than that of freshly digested sludge. Environmental sampling of well water, streamwater, soil, and crops helps to measure hazards, but tells little about the sludge as applied, because of the strongly modifying effects of exposure and percolation. No air samples have been taken to determine biological or chemical composition of the aerosols. This study is thereby deprived of the knowledge of what is present and of what quantity. The first might be surmised if thorough sludge analyses (as sprayed) were available, though with considerable uncertainty about labile microorganisms. The second could be estimated for stable chemical constituents only.

3. Human Health Implications from Indirect Evidence

The most useful indirect information concerning the Fulton County project is the absence of reported health effects. As this situation continues, the probability of serious trouble clearly diminishes. However, future high levels of pathogens or toxic substances in the sprayed sludge could result from a severe epidemic, changed industrial processes, defective treatment plant operation, or abbreviated sludge holding time. Lack of evidence concerning health effects is apparently based on absence of conspicuous ill effects rather than an active medical search for indicators. For example, serological evidence of immune levels might point to subinfective exposure, medical records might show abnormal incidence of respiratory disease in the vicinity, or occupational health records might reveal cases where exposure at home had tipped the balance of response by augmenting occupational exposure to an industrial chemical.

Despite these reservations, the missing evidence is encouraging and correlates with experience elsewhere (Viraraghavan, 1973; Sorber, 1973; Benarde, 1973; Krishnaswami, 1971; Dixon and McCabe, 1964; Anders, 1954; Browning and Gannon, 1963; Ledbetter et al., 1973; Illinois Advisory Committee, 1975). Note, however, that the evidence indicates the level of risk to be low rather than nonexistent.

There is no doubt that the influent wastes at treatment plants contain a wide range of pathogens (see, e.g., Viraraghavan, 1971; McCoy, 1971) that are not totally destroyed by treatment, including chlorination (Sorber, 1973; Kruze et al., 1960). Although holding the sludge further reduces pathogens, there is no evidence that it eliminates them entirely, and toxic metals and other chemicals may remain in sludge in significant concentrations. Also, there is evidence that operations which release small droplets do generate bacterial aerosols at treatment plants (Kenline and Scarpino, 1972; Adams and Spendlove, 1970; Napolitano and Rowe, 1966; Albrecht, 1958; Randall and Ledbetter, 1966). There is, therefore, reason to believe that pathogens might exist in the sludge as sprayed and that toxic substances certainly do, and spraying will definitely result in downwind aerosol transport of sludge constituents.

Another possible mode of transmission that could affect both man and animals is by insect vector. Any irrigation operation resulting in standing water containing pathogen-contaminated sludge presents a potential hazard (Sorber, 1973). There are no data to support an evaluation of this risk for Fulton County, but it may be surmised that the risk is small or negligible. The initial concentration of any pathogen would not be high and would be likely to decay rapidly in exposed shallow water. In addition, the stagnant water is unlikely to remain for long periods of time, so the chances of infecting vectors are low.

4. Animal Health Implications

Domestic and wild animals are also subject to airborne exposure, and waste reaching treatment plants may contain a wide range of pathogens and parasites capable of affecting animals exclusively. However, there is another route for transmission of biological and chemical agents which may be directly transmitted through ingestion of fodder plants coated with sludge spray. (This is explored in Chapter IX.)

C. MEASURES TO PREVENT OR MITIGATE DIRECT HEALTH HAZARDS

Recommendations are of two types: actions which would support a more thorough evaluation of the hazards, and actions which can be taken to reduce known or suspected hazards.

1. Improved Evaluation of Hazards

Literature on epidemiology of sludge spray irrigation and similar operations should be more thoroughly reviewed. Useful evidence may be found, especially in foreign journals. Further evidence from wastewater treatment plants is not needed. Public health records should be analyzed and data collected on industrial discharges to provide a better identification of the original inputs into the wastewater system. This information should be examined for correlation with the sludge analyses to guide future controlling actions in the event of increased pathogen or toxic substance loads.

Biological and chemical analysis of sludge as sprayed should be conducted. Air sampling should be performed downwind of the spraying operation, concurrently with the foregoing sludge analysis. Conditions favoring a risk should be selected: low temperature, stable atmosphere, light wind, overcast day. Although less important than on-site sludge analysis, biological and chemical analysis of sludge leaving the treatment plants would provide baseline information concerning the input to the on-site storage and spraying operations, and supply better knowledge of the hazards attendant on short-circuiting the holding stage.

2. Reduction of Known or Suspected Hazards

The following measures are recommended for preventing or ameliorating hazards to human and animal health:

- Entirely eliminate sludge spraying in favor of soil incorporation and spreading techniques. This would eliminate the aerosol hazard.

- Minimize wind drift by designing spray equipment for low spray nozzle velocity and discharge near the ground. Operate in moderate to low wind with high turbulence to favor dispersion.

- Reduce downwind survival of pathogens by operating in conditions favoring viable decay: low windspeed, warm temperature, daylight. Avoid stable, cool air in overcast or dark.

- Minimize pathogen content at the time of spraying by longer retention in sludge lagoons and Fulton County holding basins. Watch for local peak hazards by public health liaison and monitoring of pathogens and toxic substances at the treatment plants, increasing holding time if necessary. Ensure that holding procedures cannot be short-circuited.

- Confine sludge sources to non-industrial sewage or pretreated industrial wastewater in order to minimize toxic heavy metals.

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IX. INDIRECT HEALTH EFFECTS OF THE PROJECT

This chapter examines the potential indirect health effects of the project, such as those caused by the consumption of vegetables or meats contaminated by pathogens or heavy metals in sludge. The chapter begins with a discussion of theoretical considerations such as the interaction between sewage sludge and soil, and identifies potentially hazardous constituents. The potential for biomagnification of toxic substances in the food chain is then discussed in detail, beginning with an assessment of the accumulation of toxic substances in soil, and proceeding to each trophic level until human health implications are addressed. The chapter concludes with suggestions of measures to prevent or mitigate indirect health effects.

A. THEORETICAL CONSIDERATIONS IN ASSESSING INDIRECT HEALTH EFFECTS

Sludge applied to land has a variety of effects upon the soil. The first part of this section discusses the types of interactions that occur between sewage sludge and soil, and the second part examines the behavior of nutrients and trace elements in the soil.

1. Sewage Sludge and Soil Interaction

An overview of the sources of interaction of sludge components in the food chain is depicted in Figure IX-1. Sewage sludge undergoes many types of reactions after being incorporated into soil. These general reactions are illustrated in Figure IX-2. Reaction rates and conditions are governed by soil type, cover crop, and environmental characteristics such as temperature, ion exchange capacity, organic matter, soil organism loading, and so forth. Some interactions are known, but most are only guessed at. There are no models available which can be used to make predictions about the effects of sludge on various soil and plant components or characteristics. This section first identifies the variables affecting these interactions and then examines the effects of sewage sludge on soil structure, erosion, and the soil atmosphere.

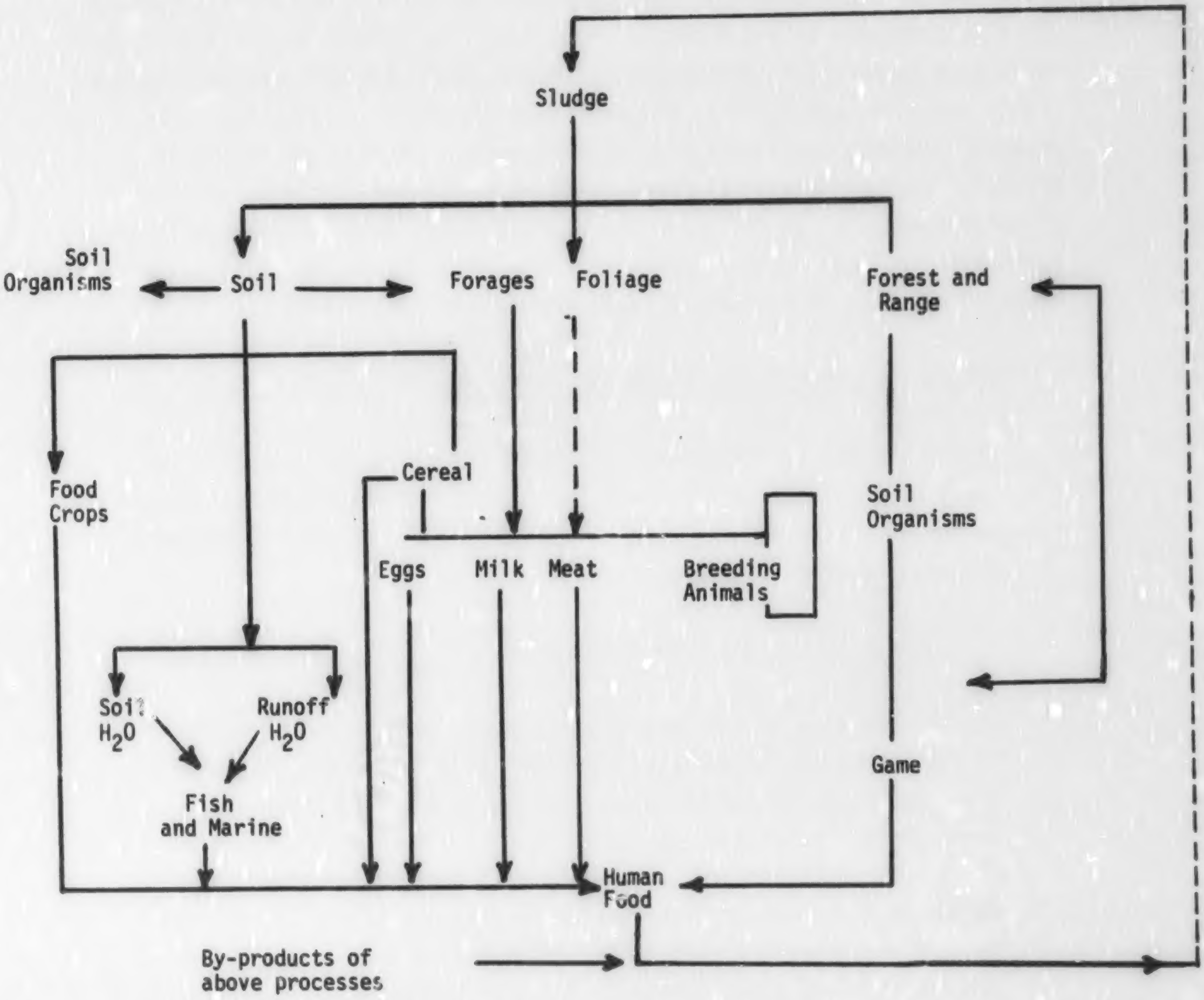
Sludge
Soil Organisms
Soil
Forages
Foliage
Forest and Range
Food Crops
Cereal
Soil Organisms
Eggs
Milk
Meat
Breeding Animals
Soil H_2O
Runoff H_2O
Game
Fish and Marine
Human Food
By-products of above processes

Figure IX-1. Sources of Interaction of Sludge Components in the Food Chain (Enviro Control, Inc., 1976)

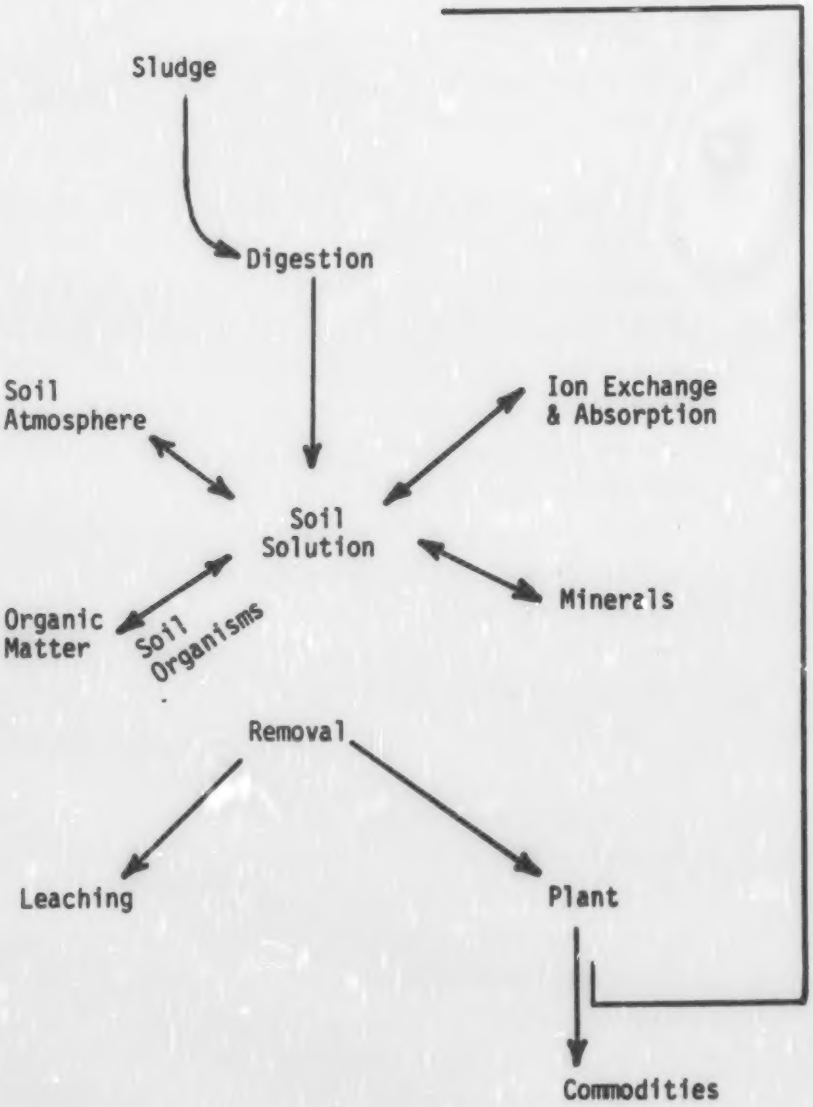
Sludge
Digestion
Soil Atmosphere
Ion Exchange & Absorption
Soil Solution
Minerals
Organic Matter
Soil Organisms
Removal
Leaching
Plant
Commodities

Figure IX-2. Major Interactions of Sludge and Soil Constituents (Lindsay, 1972).

a. Factors in sludge and soil interaction - Soil type is the primary factor in determining the effects of sludge on soil. The texture of the original soil from the strip-mined land ranged from loam to clay loam. During stripmining, the overburden, including loess, glacial drift, limestone and shale, was mixed as spoil. This material was further mixed by subsequent leveling and grading as part of land reclamation. Efforts were made to minimize damage during reclamation by leveling and burying ridges of shale, limestone and claystone.

Chemical and physical sludge properties are also of prime importance in determining effects upon the soil. Depending upon the season, treatment plant output, shipping schedule, and other constraints, the sludge shipped to Fulton County may be fresh from digestion or it may have been mixed at variable concentrations with high-solids sludge from storage lagoons. Sludge may have been stored for up to 20 years in these lagoons. Physical and chemical properties of the sludge as shipped are shown in Table VII-3 (page VII-10). In the past, because of Fulton County facility constraints, barged sludge may have been pumped into, and supernatant effluent pumped out of, the same storage basin concurrently. This should not occur under current operating procedures as separate storage lagoons are planned to be used. This will result in a minimum storage time of six months.

Effects of sludge upon soil are determined to a great extent by application rates. Sludge application to strip-mined land is authorized on a sliding rate scale of 75 dry tons per acre for the first year, and 25 tons per acre for the following years. Because sludge application rates must be modified according to climatic and cropping conditions, maximum spreading rates are seldom reached. For the coming year, sludge will be incorporated at a maximum rate of 25 dry tons per acre in five to six applications to non-cropped land. Cropped land will receive approximately half that amount in three applications (two pre-planting and one post-harvest). Sludge application rates and their effect on a specific soil type must be studied under actual conditions, because inadequate data exists to accurately predict effects.

b. Effects upon soil structure, erosion, and the soil atmosphere - Sludge application has physical as well as chemical effects on soils. These physical effects are mainly the result of the high content of organic matter in sludge, which directly influences soil structure and indirectly influences other soil properties, such as aeration. The interactions between sludge and physical soil characteristics are so numerous as to preclude an overall analysis. Hence, effects are evaluated in terms of soil aggregation, infiltration rates, soil aeration, and others.

Organic matter improves soil properties by providing a matrix for ionic loading and water adsorption. This increased nutritive capacity results in increased productivity. In fine textured soils, sludge organic matter provides a matrix for the formation of a stable structure. Figure IX-3 below shows the effect of sludge on stable aggregate formation. The influence of organic matter on aggregation probably reflects a combination of both direct and indirect effects. The indirect effects are observed through the influence of soil organisms upon soil aggregation, particularly fungi, actinomycetes, and bacteria (Hubbell and Staten, 1951).

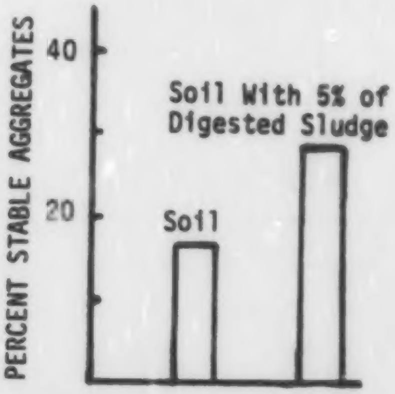

Figure IX-3. Effect of Sewage Sludge on Stable Aggregates (Hubbell and Staten, 1951)

Increased aggregate stability results in increased infiltration and permeability rates, increased aeration porosity, and decreased bulk density. These properties, in turn, influence soil erosion potential, the soil atmosphere, and the types of reactions occurring in the soil. Erosion potential decreases with increased water infiltration rates and stabilization of soil particles, with a resulting decrease in dislodgement and filtration. In addition, a surface layer of organic matter reduces the energy of raindrop or spray droplet impact. Reduced erosion may be among the most positive benefits derived from sludge application.

The soil atmosphere is affected by sludge application, primarily through the effect or organic matter on microbiological populations (Wakeman, 1932). The soil atmosphere controls the types of reactions occurring within the soil. Anaerobic conditions favor denitrification while aerobic conditions favor nitrification. Ethylene gas, methane and carbon dioxide may accumulate in soil under anaerobic conditions (Russell, 1961). This, in turn, affects the uptake of water and nutrients by plants. For example, potassium uptake is reduced under high carbon dioxide conditions. The uptake of Ca, Fe, Mg, and Ni are affected to a lesser degree. Effects on other elements have not been extensively examined. Sludge application also affects gaseous diffusion, which is directly related to soil porosity (Erickson, 1973), as well as soil heat uptake and water evaporation. It should also be noted that sludges with high sodium concentrations may have a deleterious effect upon structured soils through a dispersion effect, as well as creating conditions for potential salt toxicity.

The organic matter in the soil of Fulton County strip-mined land begins at an extremely low level and increases on a long-term basis until it reaches a steady state equilibrium. The maintenance level of sludge application (25 dry tons per acre per year) provides maximum nitrogen utilization by crops, and should supply sufficient organic matter for further improvement of soil structure, although possibly at an artificial level. If sludge were not added after equilibrium was reached, the residual soil organic matter would presumably decompose and decrease on a log scale until a new equilibrium, consistent with agronomic practices, was reached. Probably some soil structure would be lost (Peerlkamp, 1950). If the land lay fallow, organic matter may decrease to near the original level as bacterial populations are altered. This could have a dramatic effect upon mineral availability, because most trace minerals in the soil are absorbed onto or chelated by soil-organic matrices.

The above change, coupled with a concurrent decrease in soil pH, loss of buffering capacity and basic elements, and alteration of conic complexes, could drastically increase the availability of trace elements. This is a primary cause for scientific concern about indiscriminate application of sewage sludge to land. Data does not exist to confirm or refute this hypothesis.

If soil erosion occurs in the future, environmental impacts from sludge application could be severe. Estimates of normal yearly soil loss range up to 1.5 tons per acre (or 10,000 tons/mi^2). Losses of 30 tons per acre have been recorded on specific small watersheds (Bondurant, 1970). Since erosion of farmland occurs mainly on the surface zone, which is analogous to the area of mineral accumulation, soil erosion may remove sizable quantities of trace metals from land applied with sludge. Runoff and soil erosion have also directly correlated with herbicide application. Herbicides are used extensively on reclaimed land to control severe weed infestation (Hall, 1975, personal communication). Catch basins and soil conservation practices presently control this problem, but future problems may occur.

2. Behavior of Nutrients and Trace Elements in Soil

Nutrients can be classified as soluble, intermediately soluble, or relatively inert. Water from sludge and rainfall carries soluble constituents while percolating through soil drainage channels. These constituents consist mainly of Na^+, K^+, NH_4^+, Ca^{+2}, Mg^{+2}, Cl^-, SO_4^{-2}, NO_3^{-2}, HCO_3^- and H_3BO_3, all of which can cause potential problems. The effect of sodium on soil structures was cited earlier. With either high rainfall and/or irrigation, these solids may leach, resulting in pollution of the water table (Richards, 1954).

Soluble cations are capable of exchanging with others where the rate is governed by ionic activity. The major cations of high solubility and activity are Ca^{+2}, Mg^{+2}, Na^+, K^+, and, in acidic soils, Al^{+3} and H^+. A partial list of ions classified as having intermediate solubility includes ionic forms of As, Cd, Co, Cu, Hg, Mo, Ni, P, Pb, and Se. Although considerable work has been done with these elements, much is unknown about their specific solubility, precipitation processes and interactions. A third group of ions form relatively inert components in soils, and are not generally influenced by soil-plant interrelationships. This group includes ions such as Cr^{+3}, Fe^{+3}, and Mn^{+4} which form insoluble oxides.

Accumulation of nutrients and minerals in the soil is an inevitable result of disposing sludge on the land. As a rule, plants do not accumulate large quantities of soil elements other than nitrogen, phosphorus and potassium, and the actual quantity removed permanently from the soil by commercially salable products is small even for these. Chemical analyses of soil for total and available nutrients after sludge application were unavailable at the time of this writing. By examining soil composition prior to land leveling or after leveling, after initial high-level sludge application, and with succeeding sludge application rates, the effects of sludge application as a function of total and available elements could readily be evaluated.

This section discusses the relationship between total and available nutrient concentrations in the soil, and then identifies elements of potential or minimal hazard.

a. Total and available soil concentrations - The important concept in evaluating the effects of sludge application is not the loading rate of an element per se, but the availability of the element in the soil matrix. After sludge is applied, precipitation and other reactions affecting the activity of an element may take several weeks or longer to reach equilibrium (Patterson, 1966; Webber, 1972; Curry and Gigliotti, 1973; Lehman and Wilson, 1971; Leeper, 1973). When evaluating the potential effects of an element, the oxidation state, the presence of other ionic elements, chelating agents, and the soil organic matrix must be considered.

The availability of an element in the soil matrix can be experimentally estimated by periodically taking soil samples and performing analyses using standardized procedures (Standard Methods for the Examination of Water and Wastewater, 1965). The data derived allow the determination of availability as a percent of a total element present, which should roughly agree with the total soil loading from sludge application after correcting for original soil loads and crop removal. If it does not, a loss through leaching or some other process should be suspected.

b. Heavy metals of potential hazard - Copper, nickel and zinc are usually present in sludge in small quantities and in various insoluble forms. Solubility is directly related to pH (Lindsay, 1972). The addition of these elements to the soil may actually be beneficial as they are often deficient in foods for human consumption. At very high levels of availability, these elements can be toxic to plants and animals. Cadmium apparently behaves in a manner similar to copper, nickel and zinc. It may be the major problem in applying sludge to Fulton County land because of its high concentration especially in relation to the zinc content. USDA recommendations and draft EPA regulations would limit the Cd level in sludge to 1% of the Zn content. The rationale for this proposal is that Zn plant toxicity would occur and be noticed before Cd in the plant reached a level potentially harmful to human or animal health. Others feel that this level of Cd is too high and does not provide an adequate safety factor for routine unmonitored use.

Chromium behaves similarly to other elements such as zinc. It is normally found as Cr^{+3} in insoluble hydroxides. Low pH and reducing conditions should increase its availability, perhaps resulting in plant toxicity. Proper management will eliminate this problem. Lead forms relatively insoluble compounds in soil, including $PbCO_3$, $PbSO_4$, and $Pb_3(PO_4)_2$ under normal conditions. Solubility is probably directly related to soil pH and redox potential. Lead may present a problem, especially in sludge originating from treatment plants where urban storm runoff and sanitary sewage are combined.

c. Mineral elements of minimal hazard - Nitrogen is presently the limiting element for sludge application in Fulton County. Soil nitrogen is derived from organic residue as NH_4^+, which is rapidly oxidized to NO_3^- by soil bacteria. Under reducing conditions, NO_3^- may be converted to NO_2^-, N_2, and N_2O. The gases NH_3, N_2 and N_2O may escape from the soil as denitrification losses. From 15 to 50% of sludge nitrogen may be lost in this manner. Normally, soil nitrogen is in the anionic NO_3^- form and moves as a solution in groundwater. Nitrogen toxicity to plants or groundwater pollution can be eliminated by proper management.

Phosphorus usually forms insoluble complexes with Al and Fe, or at higher pH with C or Ca (Lindsay and Moreno, 1960). Since phosphorus is a major constituent of sludge, it may also become a limiting element, especially after several years of sludge application. Phosphorus toxicity in soybeans has been observed (University of Illinois and MSDGC Department of Research and Development, 1975). High levels of phosphorus may be toxic per se, or may create nutrient imbalances resulting in deficiencies of other elements (Olsen, 1972).

The limiting factor for phosphorus uptake is Al, Ca, and Fe levels, which usually exceed needs. The other aspect of the potential phosphorus problem is the presence of detergent polyphosphates and the organic phosphates used in insecticides and herbicides.

Calcium, magnesium, potassium and sodium are usually major soil constituents and generally present no problem unless applied at extremely high levels. Normal leaching processes will remove these elements by ionic exchange mechanisms, but their loss should not pose a greater hazard than that associated with mine spoils. Iron and manganese occur in abundance in natural soils, normally in the form of insoluble hydroxides and oxides. The addition of sludge should not, therefore, cause any problems unless the soil is allowed to become acidic. Under these and reducing conditions, the elements become solubilized and may cause toxicity and pollution problems which can also be controlled by management. Sulfur exists as the sulfur anion except under anaerobic reducing conditions. It is known to play a role in metal uptake by interacting with other elements.

B. POTENTIAL INDIRECT HEALTH HAZARD OF BIOMAGNIFIED TOXIC SUBSTANCES

This review of potential indirect health effects resulting from sludge application to strip-mined land is structured into several sections. First, the accumulation of sludge components by soil and plants, with an emphasis upon corn, soybeans and grasses, will be evaluated. The potential accumulation of sludge components in milk, beef, pork and chicken will be discussed second. The next area of interest is the accumulation of components by wildlife or soil animals. The former could be represented by deer and rabbits, and the latter by gophers and worms. All of the above factors play a role in the evaluation of hazards to the last group and major concern of this study — humans.

Assessment of problems is confounded not only by lack of data, but by continued modification and alteration of sludge handling and disposal procedures. For the coming years, 85% of the worked acreage is supposed to have sludge incorporated into the soil by disking or plowing operations to a depth of 8 to 10 inches. Spraying will be utilized on 15% of the interior land in four fields. Two will be planted to alfalfa-brome mixture for winter pasture and two to Sudax for summer pasture. These fields will then be "field grazed" by 87 head of beef cattle over the year.

1. Evidence of Accumulation in Soil

This section presents evidence of accumulation of both heavy metals and organic compounds in the soil.

a. Concentrations of heavy metals - As a point of reference, 1968 FWPCA water quality criteria for irrigation water were compared with the composition of sludge applied betweeen May 1974 and October 1974, using the maximum monthly average application rate. The ratios of sludge concentrations of Cd, Co, Cr, Cu, and Zn to the FWPCA limits for short-term irrigation of fine-textured soil reveal one outstanding difference: Cd is 276 to 1 or about 16-fold greater than the next highest ratio, which is for zinc (17 to 1). This indicates tremendous cadmium enrichment relative to zinc. Table IX-1 on the following page compares typical amounts per acre of soil constituents with amounts added in 200 dry tons of sludge (maximum annual rate per acre). Again, one dramatic difference is apparent. The sludge-to-soil ratio for cadmium is 1,400, which is 29 times greater than the next highest ratio, and 56 times greater than the ratio for zinc. These same calculations could be made for Fulton County soils if sufficient data were available.

Table IX-1. Comparisons of Normal Soil Constituents to a Sludge Loading Rate of 200 Dry Tons per Acre (Bowen, 1966)

Element	Amount in Sludge (mg/kg)	Amount added to Soil (kg/ac)	Amount Present in Soil (kg/ac)		Sludge-to-Soil Ratio*
			Normal Range	Typical Level	
Cd	350	70	0.01-0.6	0.05	1400
Cr	4450	980	4-2500	80	11
Cu	1800	360	1-80	16	22
Pb	1720	344	2-160	8	43
Mn	400	86	80-3500	700	0.01
Hg	8	1.2	0.01-0.25	0.025	48
Ni	350	70	80-800	30	2
Zn	5000	1000	8-250	40	25

* Ratio of amount in 200 dry tons of sludge to typical soil level

Data published on the build-up of trace metals in soils (see Tables IX-2 and IX-3) show discrepancies between experimental and theoretical findings. In Table IX-2, accumulations of extractable trace elements are shown for soil treated with 76 tons of sludge over 12 years, indicating that contamination problems can develop. The analysis shows the sludge to be high in copper and mercury, but extremely low in cadmium. The percent recovery is a reflection of element availability and shows an increased mineral pool available to the plants, presumably originating from sludge. This indicates that mineral reversion and binding may not be as extensive as many hypothesize. The last column reflects element application rate as a percent of control soil and shows an extremely high loading rate of mercury.

Table IX-2. Changes in the Concentrations of Extractable Trace Elements in Soil Following Application of 76 Tons of Sewage Sludge Over a Period of 12 Years (Anderson and Nilsson, 1972)

Element	Sludge	Control Soil	Treated Soil	Total Amount Applied[1]	Recovery[2]	Application[4]
	mg/kg	mg/kg	mg/kg	mg/kg	(%)	(%)
Mn	373	476	480	11.8	98	2
Zn	4,890	97.9	368.8	154	146	157
Cu	1,960	25.5	90.5	61.9	104	243
Ni	88	28.2	43.3	2.78	140	10
Co	12.2	14.2	14.6	0.38	100	3
Cr	176	36.1	61.0	5.56	146	15
Pb	293	25.7	43.9	9.25	125	36
Cd	11	1.2	1.7	0.35	110	30
Hg	12	0.018	0.675	0.38	170	211
Mo	7.4	0.53	0.68	0.23	89	43
As	6.6	12.3	12.5	0.21	100	3
B	30	0.59	0.76	0.95	49[3]	161
Se	7.3	0.238	0.569	0.23	121	97

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[1] Assuming the bulk density of the soil was 1.33. Except for boron, percent recovery is based upon concentrations extracted with 2 M mineral acids.

[2] Within the surface 20 cm of soil. Losses are due to plant removal, leaching and possibly erosion.

[3] Refers to recovery of water soluble boron.

[4] Amount applied as a percent of control soil.

Table IX-3. Element Analysis of Sludge and Top Six Inches of Soil (Hinesly *et al.*, 1972)

Element	Sludge Application (mg/Kg soil)		Total Element in Soil Sludge Application Rate (tons/ac)			Extractable Element in Soil Sludge Application Rate (tons/ac)		
	37	75	0	37	75	0	37	75
			(mg/Kg soil)			(mg/Kg soil)		
Ca	1362	2747	3,000	3,100	3,100	1200	1200	1500
Fe	2023	4046	18,300	18,000	18,500	499	792	775
Mg	397	794	2,700	2,800	2,500	400	413	410
Mn	25	49	1,200	1,400	1,500	304	428	402
K	175	351	18,000	17,800	18,200	222	229	260
Na	84	166	5,900	5,900	6,000	14	27	32
Zn	285	570	72	163	260	13	98	181
Cu	74	148	19	34	52	3.9	19	32
Pb	63	126	31	44	60	6.6	17	30
Cr	177	354	29	61	86	.9	11	19
Ni	18	36	23	25	28	2.3	5.3	7.0
Cd	20	40	1.1	5.1	8.5	0.2	3.8	7.0
			(0.1)*	(4.1)*	(7.5)*	(0.02)*	(3.6)*	(6.8)*
Hg	0.025	0.05	0.04	0.15	0.27			

* See comment in accompanying text.

Table IX-3 shows sludge, total soil and extractable soil concentrations of elements for the top 15 cm of soils on sludge-treated land. Total and extractable elements are increased for all of the trace elements reported. Since there may have been an error in the determination of the Cd level in this experiment, a second line is included, showing that total Cd increases sevenfold with a high background value, but 75-fold with a low background value. The same relationship is obtained for extractable Cd, with a 35-fold increase for a low background value. Table IX-4, displayed below, presents the data in a different perspective, where the extractable pool is calculated as a percent of the total pool. The percent recovery of trace elements in the sludge applied to the soil is also shown, indicating that element loss is high. Assuming that the techniques are valid, element loss occurred through plant uptake, leaching or soil erosion.

Table IX -4. Recovery of Trace Elements as a Function of Trace Elements Applied (Hinesly *et al*., 1972, 1974)

	Sludge Application Rates (dry tons per acre)				
Element	0	37	75	37	75
	Element Availability (extractable element/total element)			Recovery in 0-15 cm depth*	Recovery in 0-15 cm depth*
	(%)	(%)	(%)	(%)	(%)
Cd	22	78	83	17	15
Cr	3	17	21	16	13
Cu	23	56	61	16	19
Pb	--	21	35	17	19
Ni	10	21	25	10	11
Zn	18	60	68	27	35

*Assuming that all elements applied remain in the 0-15 cm layer.

In another study, trace element concentrations extracted from soils treated with sewage sludge for 19 years were compared with samples from untreated control sites and from the sludge applied (see Table IX-5). Considering that application of sludge was discontinued in 1961, the 1967 analyses indicate long-term availability of these elements. It is apparent that sludge loaded elements will be available for plant uptake for a considerable period of time. The soil onto which the sludge was applied had greater than normal concentrations of Cu, Ni, and Zn. The level of zinc in these sludge-treated soils may be toxic to susceptable crops (Purves, 1972).

To evaluate the leachability of various elements from sludge-treated mine spoils, laboratory soil columns with three sludge application rates were leached for 100 days (see Table IX-6). The extractable elements were determined at various depths after leaching. Note that sludge incorporation was uniform. It is interesting that extractable quantities of each element vary with depth and sludge loading rate. This shows the difficulty in predicting the behavior of any particular element under specific conditions.

Table IX-7 records the concentrations of elements at two depths with four sludge loading rates. The data clearly show accumulations of weak extractable elements with increasing sludge application rates for both sampling depths. It also shows that most elements are concentrated in the upper layer of soil. Available cadmium and chromium disclose the largest increases of 20 and 35 times background levels, respectively, indicating the need for careful monitoring under these conditions. All trace elements need to be monitored periodically for both total and extractable levels. Particular emphasis needs to be placed on Cd, Cr, Cu, Pb, Hg, Ni, and Zn in all cases, and others depending upon the composition of the sludge. Much needs to be learned about the behavior of trace elements from sludge when applied to soil.

Table IX-5. Trace Elements Extracted by 0.5 N HOAc from Soils Treated with Sewage Sludge for 19 Years and the Sewage Sludge Applied, and Compared with Normal Scottish Soils

Description	Concentration Extracted by 0.5 N HOAc[2]				
	Cr	Cu	Pb	Ni	Zn
	Hg/g				
Sewage Sludge Applied	3.5	20	3.2	50	800
Control:					
Sampled in 1959	0.3	5	1.2	4.2	88
Sampled in 1967	0.9	15	1.6	4.4	83
Treated[1]:					
Sampled in 1959	2.8	20	5	18	395
Sampled in 1967	2.6	58	4.2	8.1	275
Normal Scottish Soils[4]					
Low	0.01	0.05	0.2	0.1	2
High	1.0	1.0	4.0	5.0	30

[1] From Le Riche (1968). Sewage was applied annually at an average rate of 66.5 tons per year for 19 years.

[2] Results are the mean from 2 plots.

[3] Treatments were discontinued after 1961. In 1959 and 1967 the total sludge was 1,260 and 1,393 m. tons/ha, respectively.

[4] From Mitchell (1964).

Table IX-6. Concentrations of Various Trace Elements Extracted From Sludge-Amended Acid Spoil Mine Material (Peterson and Gschwind, 1973)

	Spoil	0.1 N HCl Extractable			
Treatment*	Depth	Cr	Cu	Mn	Zn
(m. tons/ha)	(cm)	Hg/g			
Control		4.3	14	8.0	54
61	0-10	20	33	7.7	136
	10-20	3.5	5.5	3.5	145
	20-30	77	126	21	556
	30-40	78	127	19	488
122	0-10	52	80	12	104
	10-20	51	67	10	206
	20-30	5.2	7.1	5.5	113
	30-40	3.8	6.4	3.8	70

*Sewage sludge was incorporated uniformly to 2 kgm of spoil material rates indicated.

Table IX- 7. Concentrations of Trace Elements Extracted With 0.1 *N* HCl from Sludge-Amended Soils (Hinesly *et al*., 1972)

Application Rate (m. tons/ha)	Concentration in Soil (Hg/g)						
	Cd	Cr	Cu	Pb	Mn	Ni	Zn
				0-15 cm depth			
0	0.2	0.94	3.9	6.6	304	2.3	13
44	1.5	3.3	8.4	11	306	3.5	41
88	3.8	11	19	17	428	5.3	98
166	7.0	19	32	30	402	7.0	151
				30-45 cm depth			
0	0.6	0.6	3.5	2.0	45	2.6	7.8
44	0.7	0.8	4.9	2.7	63	3.6	12
88	0.8	1.3	5.9	4.2	57	3.6	16
166	0.9	1.6	6.4	5.3	61	3.6	18

The use of sewage sludge in reclamation of strip-mined land for agricultural purposes may be a significant hazard due to heavy metal accumulations in food plants and animal produce. The elements most likely to cause problems are As, Cd, Pb, and Se, with Cd posing the greatest hazard considering the relative concentrations in the applied sludge. A complicating factor is high background levels of certain heavy metals in mine spoils. University of Illinois researchers pointed out that the black shale overlying the coal seam had been considered a heavy metal mining resource (Hinesly, 1975, personal communication). Since it was interspersed within the overburden, it may contribute significantly to the heavy metal load in soils.

b. Concentrations of organic compounds - Relevant data could not be located concerning the levels of organic compounds in sludge, let alone the accumulation of these compounds in sludge-treated soils. One exception is humus-related material, which directly affects water and mineral retention and is easily studied. Accumulation of humus is governed by its equilibrium with soil bacteria. As more organic carbon is applied and more soil organisms are present, more organic carbon is degraded. However, quantitative information on this process sufficient for reliable predictions is lacking, as is information concerning the effects of arbitrarily halting sludge applications. These data are necessary to predict the hazard from trace metals once sludge application is discontinued.

Another concern with organic compound accumulation which may eclipse humus in importance is the build-up of organic contaminants such as fats and oils, chlorinated hydrocarbons, herbicides, biologically active metals such as methyl-mercury, and others. Although data was insufficient to assess potential effects of these organic contaminants, such effects are known to exist in other cases. Therefore, a potential hazard could be assumed to exist in Fulton County.

2. Evidence of Accumulation in Plants

Since research has shown that total and available minerals accumulate in sludge-treated soil, the potential for accumulation and concentration of minerals in plants grown in such soil must be assessed. Fulton County is in a prime agricultural region where the predominant crops are corn and soybeans. These two crops will therefore be analyzed in this section, along with grasses, which could serve as forage or ground cover.

Data presented in Table IX-8 show typical concentrations of trace elements in soils as compared to levels in plants. Suggested toxic levels for "average" plant species are proposed (i.e., ignoring accumulator species). The problem with interpreting this data is that there is no way to predict availability and uptake of elements.

a. Concentrations in corn plants - Analysis of trace element accumulations in corn plants and leaves is given in Table IX-9 for four sludge application levels. The data reveal definite accumulations of Cd and Zn in corn leaves. Mn and B also accumulate but to a lesser degree. Zn and Cd levels in grain are increased with increasing sludge application, whereas Mn and N show no significant change at the sludge application rates used. Assuming that these Cd values may be in error, accumulation of Cd would be even greater than is indicated. The validity of this assumption is supported by USDA research which reports the Cd level for corn samples to be 0.035 to 0.148 with a mean of 0.055 ± 0.043 mg/kg (Garcia *et al.*, 1974). This data indicates that there is a definite potential hazard from mineral accumulation in corn grain and plants.

From the available data, cadmium appears to be the most potentially detrimental element in grain. If the corn plants were harvested as silage for animal consumption, many elements could present problems. In similar laboratory work, Zn and Cr were both found to be toxic to corn plants, but at extremely high levels which would probably require long-term sludge application (Mortvedt and Giodano, 1975).

Table IX-8. Concentrations of Trace Elements in Soils and Plants (Allaway, 1968)

Element	Concentration in Soils (μg/g)		Concentration in Plants (μg/g)	
	Common	Range	Normal	Toxic*
As	6	0.1 -40	0.1 -5	--
B	10	2 -100	30 -75	75
Cd	0.06	0.01-7	0.2 -0.8	--
Cr	100	5 -3,000	0.2 -1.0	--
Co	8	1 -40	0.05-0.5	--
Cu	20	2 -100	4 -15	20
Pb	10	2 -200	0.01-10	--
Mn	850	100 -4,000	15 -100	--
Mo	2	0.2 -5	1 -100	--
Ni	40	10 -1,000	1	50
Se	0.5	0.1 -2.0	0.02-2.0	50-100
V	100	20 -500	0.1 -10	10
Zn	50	10 -300	15 -200	200

*Toxicities listed do not apply to certain accumulator plant species.

Table IX-9. Content of Trace Elements in Corn Versus Levels in Sludge (Hinesly *et al.*, 1972)

Element	Sludge Application (Kg/ac)	Corn Leaf (mg/Kg)	Corn Grain (mg/Kg)
Fe	--	107	100
	1,639	101	95
	3,279	111	106
Mn	--	81	18
Zn	20	92	11
	40	116	18
Na	--	96	146
	77	111	99
	134	94	232
Cr	--	4	0.3
	143	5	0.3
	287	4	0.4
Cu	--	9	5
	60	10	5
	120	9	6
Pb	--	7	0.03
	51	7	0.04
	102	6	0.03
Ni	--	3	2
	14	3	3
	29	4	3
Zn	--	58	89
	231	138	127
	462	212	152
Cd*	--	3	0.3
	16	5	0.8
	32	12	1.0
B	--	26	7
	2	35	5
	4	44	7
Hg	--	0.03	0.005
	0.017	0.03	0.005
	0.033	0.04	0.004

*Baseline data may be erroneous by a factor of 10x.

b. Concentrations in soybean plants - Application of sludge to soybeans has demonstrated that serious problems could develop. When sprayed on soybean fields, sludge accumulates on the leaves and results in decreased photosynthesis. The nitrogen-fixing bacteria living symbiotically with legumes are eliminated. In addition, soybeans are extremely susceptible to salt and phosphorus toxicity. This was observed when 105 tons of MSDGC sludge were applied to Blount silt loam. The toxicity was reduced by leaching, which presumably reduced the soluble salt load in the soil (Thorne and Hinesly, 1975).

Soybean plants have been shown to accumulate Cd from sludge-treated soils (Jones et al., 1973). The addition of 87 metric tons per hectare produced Cd levels in plants of 18.5 µg/l as opposed to 1.8 µg/l at the control plot. Seeds showed a maximum concentration of 1 µg/l. Other work summarized in Table IX-10 also indicates that soybean grains can accumulate Cd and other metals, including Cu and Zn. Presumably other elements can also be concentrated in soybean seeds.

In summary, trace element uptake has clearly been shown to occur in corn and soybeans grown on sludge-treated land in Fulton County or on similar land, as well as in laboratory and analogous field studies. Data are insufficient for predicting the long-term effects of sludge application to land. This indicates a need for continuous evaluation and prompt reporting of results prior to the release of any product for consumption by humans.

c. Concentrations in grasses and other plants - Data on grasses, including wheat and rye, disclose a large variation in mineral uptake. Uptake is dependent upon the plant species and the strain within the species (Bingham et al., 1975; Dowdy and Larson, 1975). Trace element uptake is a particular problem with lettuce, because lettuce is an accumulator. Uptake of Ni by wheat and Cu and Ni by

Table IX-10. Analysis of Soybeans Versus Total and Extractable Soil Elements (Hinesly *et al.*, 1971)

Element	Soybean Grain (mg/kg)	0.1 NH_4Cl Extractable (0-15 cm) (mg/kg)	Total (0-15 cm) (mg/kg)
Na	481	17	8,200
	591	26	7,800
	507	35	7,500
Zn	154	13	55
	174	154	244
	175	301	336
Mn	79	103	1,600
	89	305	1,300
	93	291	1,300
Cu	31	5	15
	30	51	65
	29	75	90
Cd*	0.4	0.2	1.7
	0.9	8.5	7.8
	1.2	13.6	12.3

*Baseline errors may have resulted in erroneous data.

oats is shown in Tables IX-11 and IX-12. As with other crops, soil pH and metal levels have significant effects upon plant mineral levels. The same types of effects are shown in Table IX-13 for B, Cu, Mn, and Zn in rye. In this study, Zn accumulated over 20 times more than at the control plot with increasing sludge application rates. The same pattern would probably be seen for Cd under the same conditions.

English scientists find instances of metal toxicity to plants on a routine basis on sludge-treated lands (Patterson, 1971). However, many reports of toxicity involved sludge application far in excess of that authorized for Fulton County. Toxicity was usually attributed to Zn and Ni.

Tolerance levels have been proposed for monitoring heavy metals and are shown in Table IX-14. In lieu of any nationally accepted values, these figures appear to be reasonable as a starting point. The ultimate use of a crop (i.e., human or animal consumption), subsequent dilution, and many other factors are important in determining these values.

3. Evidence of Accumulation in Domestic Animals

Two factors must be considered when examining the potential for metals accumulation in animals. The first consideration is whether the level of ingestion is sufficient to cause short or long-term toxicity or ill health symptoms. Secondly, the question of whether the biotransfer of elements via animal products is high enough to cause short or long-term toxicities in the consuming public must be considered.

The primary foods to be concerned about are milk, beef, eggs and pork or chicken. The first two commodities come from the class of animals known as ruminants, and the latter two from monogastrics.

a. Toxicity with bioaccumulation - Little data is available concerning types of metal toxicity, as animal scientists have been concerned with supplying enough rather than too much of a particular

Table IX-11. Effect of Ni Applied to Soils at Different pH Levels on the Ni Content of Spring Wheat (Patterson, 1971)

Ni Applied	Concentration of Ni in Plants Grown in Soil @ pH: 5.1	5.5	6.5	7.5
(Hg/g soil)	Hg Ni/g dry matter			
0	2.5	2.2	1.0	--
5	4.5	2.5	0.75	0.5
10	3.0	3.7	2.2	0.5
20	8.0	4.7	2.0	--
40	10.0	6.5	2.75	0.75
80	74.0	17.2	3.0	1.25
160	--	105.	8.25	3.0

Table IX- 12. Copper and Nickel Concentrations in Oat Plants as Influenced by Amount of Sewage sludge Applied and Soil pH (Page, 1974 - condensed and modified from Patterson, 1971)

Amt. Sludge Applied (m. tons/ha)	Concentration in Soil (Hg/g)[1]		Concentration in Plants (Hg/g)[2]			
			Cu		Ni	
	Cu	Ni	pH 5.3	pH 6.8	pH 5.3	pH 6.8
0	--	--	11	13	8	4
33	14	97	12	12	90	28
67	28	194	12	12	120	50
134	56	389	19	14	210	70

[1] Disregarding amount present initially; concentrations in soil are based upon air dry weight.

[2] Concentrations in plants are on a dry matter basis.

Table IX-13. Trace Element Composition and Yield of Rye Clippings As Influenced by Sludge Ayplications to Soils (King and Morris, 1972)[1]

Sludge Rate[2] (m. tons/ha)	Treatment	Yield[3] (kg/ha)	Trace Element Concentration[3] B	Cu	Mn	Zn
			Hg/g			
0	unlimed	2,000	5.0	10.0	128	32
	limed	2,120	6.2	10.2	93	30
42	unlimed	1,180	5.0	11.0	84	150
	limed	1,570	6.2	10.2	72	106
84	unlimed	1,540	8.8	12.5	133	232
	limed	1,960	6.8	11.5	89	186
121	unlimed	1,650	6.5	14.5	111	340
	limed	2,090	7.5	12.0	82	251
242	unlimed	390	8.8	20.0	227	775
	limed	900	6.5	16.0	161	579

[1] All treated with NPK inorganic fertilizer at recommended rates.

[2] Total applied on an oven dry weight (110°C) basis over a 2-year period.

[3] Dry weight basis.

Table IX- 14. Probable Available Form, Average Composition Range for Selected Agronomic Crops, and Suggested Tolerance Levels of Heavy Metals in Crops (Melsted, 1973)

	Probable Available	Common Average Composition Range (ppm)	Suggested Tolerance Level* (ppm)
		Cations	
Barium	Ba++	10-100	200
Cadmium	Cd++	0.05-0.20	3
Cobalt	Co++	0.01-0.03	5
Copper	Cu++	3-40	150
Iron	Fe++	20-300	750
Lead	Pb++	0.1-5.0	10
Lithium	Li++	0.2-1.0	5
Manganese	Mn++	15-150	300
Mercury	Hg++	0.0001-0.01	0.04
Nickel	Ni++	0.1-1.0	3
Strontium	Sr++	10-30	50
Zinc	Zn++	15-150	300
		Anions	
Arsenic	AsO_4	0.01-1.0	2
Boron	HBO_3	7-75	150
Chromium	CrO_4	0.1-0.5	2
Fluorine	F^-	1-5	10
Iodine	I^-	0.1-0.5	1
Molybdenum	MoO_4	0.2-1.0	3
Selenium	SeO_4	0.05-2.0	3
Vanadium	VO_3	0.1-1.0	2

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*Average values for corn, soybean, alfalfa, red clover, wheat, oats, barley and grasses grown under normal soil conditions. Greenhouse, both soil and solution, values omitted.

element. Table IX-15 deals with the appearance of toxic symptoms in poultry and swine. Research has shown that toxicities for most compounds are usually in the same order of magnitude for various animal species. This is generally true for initial and lethal effects and is accepted as preliminary evidence for between-species testing. Data also tends to be concerned with short-term (in the order of weeks) rather than long-term (in the order of years and decades) toxicity effects. Presumably the long-term toxic level would be considerably lower than that reported in Table IX-16.

What little data exist indicate that bioaccumulation of most trace elements does not occur in most types of livestock tissue. Absorption of trace elements is influenced by body stores of the element, the form in which the element occurs, efficiency of the digestion process (i.e., separation and breakdown of element-organic complexes), and the absorption rate.

Absorption of trace elements is rather inefficient, the maximum amount absorbed being 0 to 25% of the element intake. If an animal is biologically able to excrete more of a particular element per day than absorbed, no tissue build-up will occur unless the excretory process for that element is regulated by a metabolic mechanism. The liver and kidney may be exposed to high levels of trace elements during the excretory process. The bioaccumulation of mineral elements is known to occur in the kidney and liver of domestic animals. For food-producing animals, disposal of the kidney and liver upon slaughter eliminates the potential problem from the food chain.

In any case, this type of accumulation makes it difficult to estimate allowable animal intakes. This, coupled with variability in absorption due to nutrient intake and composition, confounds the problem even further. The excretion of trace elements by domestic animals via milk or eggs does not appear to be a problem according to limited work using I.V.-administered radionuclides.

Table IX-15. Short-Term Toxicities of Elements in Feeds

Element	Form	Chicken (mg/kg)*	Swine (mg/kg)*
Al	$AlCl_3$	500	--
Ba	--	--	--
Br	NaBr	5,000	--
Cd	$CdSO_4$	25	--
Cl	KCl	15,000	--
Cr	$Cr_2(SO_4)_3$	300	--
Co		5	--
Cu	$CuSO_4$	324	300
Fe		--	5,000
F	NaF	500	--
I	$K^{\pm}$	625	800
Mg	$MgCO_3$	6,000	--
Mn	$MnSO_4$	4,800	4,000
Hg	$HgSO_4$	400	--
Mo	Na_2MoO_4	200	--
Ni	$NiSO_4$	500	--
Pb	Pb acetate	500	--
Se	Se wheat	10	5
Ag	$AgSO_4$	200	--
Na	Na_2SO_4	8,900	--
Sr	$SrCO_3$	6,000	--
V	$Na_4V_2O_7$	10	--
Zn	ZnO	3,000	2,000
NO_3^{-2}	$NaNO_3$	900	--
NO_2^{-2}	NO_2	400	--
SO_4	$CaSO_4$	25,000	--

*Lowest level of which symptoms occur (generally decreased growth rate)

b. Toxicity with direct ingestion - The second issue in heavy metal intake by domestic animals is the direct ingestion of sewage sludge by grazing or forage-fed animals. Preliminary data (Chaney, 1975, personal communication) disclose a sludge content of up to 18% of dry matter in field-harvested forage samples irrigated with sludge. A single 13-inch rain reduces the proportion of sludge in the harvested sample to 9%. These data clearly indicate that direct ingestion of sludge via the forage from sludge-irrigated fields may pose a significant problem to animals.

A sample calculation indicates the potential problem. If sludge containing 50 ppm at 4% solids is spread on land, and assuming 10% of forage dry matter to be sludge, then Cu intake would be 125 ppm of the grazed forage. Cu toxicity symptoms may appear at 20 ppm, depending upon the effects of other elements. The intake would be six times higher than the point where toxicity symptoms may occur. Another example might be Cr intake when forage contains 4% sludge on a dry matter basis. Intake would exceed the 100 ppm level considered toxic for animals, if the sludge contained 3,000 ppm on a dry matter basis.

An analogous issue is the direct ingestion of dirt which contains high levels of trace elements. This could present a significant hazard, especially to low grazers such as sheep and to rooters such as swine.

In summary, research indicates that bioaccumulation of heavy elements from plants in animals tissues or in milk or eggs is a minimal problem. Accumulation in the liver or kidney may present a problem under certain circumstances, such as when Cd levels in feed plants and grains are high. A significant trace element problem may exist for domestic animals by direct ingestion of sludge via forage or soil. The USDA and FDA have ongoing research programs to assess the hazard level, but complete results will not be available for several years.

4. Evidence of Accumulation in Wildlife

For the purposes of this study, wildlife is divided into two categories and discussed separately. The first category consists of microorganisms and microfauna inhabiting the soil; the second consists of avian and mammalian species.

a. Soil microorganisms and microfauna - Soil microorganisms are concentrated in the top 15 cm of soil. Estimates of microorganism numbers per gram of soil are: bacteria, 10^7 to 10^9; actinomycetes, 10^6 to 10^7; fungi, 10^5 to 10^6; algae, 10^4 to 10^5; and protozoa, 10^3 to 10^5. Bacterial biomass is estimated to be approximately 2,800 pounds per acre. Actinomycetes, fungi and a combination of other soil groups each contribute an equal amount of biomass totalling 15,000 pounds per acre. Little is known about the biological role of various soil organisms, let alone their *in vitro* metabolic eccentricities and the effects of sludge application. However, one study showed significant changes in bacterial populations and in biochemical and enzymatic activity of the populations in sludge-treated land (Miller, 1973).

Soil microanimals, which include nematodes, earthworms, flatworms, snails, centipedes, millipedes, woodlice, arachnids, and insects in various stages, are also affected by sludge application. These animals probably play an important role in waste recycling on sludge-treated land (Burges and Row, 1967). Recent research (Helnke, 1975, personal communication) shows that earthworms have a heavy metal uptake which is directly proportional to contact time. Biomagnification is observed for Cd and Hg, with Cd accumulations 30- to 70-fold greater than soil concentrations. Research also indicates that earthworms are selective foragers for soil organic matter. Research is underway to determine the effects of methyl mercury on earthworms. Earlier work indicates that earthworms may accumulate lead.

b. Birds and mammals - Effects of sludge application on wild birds have not been investigated as far as can be determined. Sludge application could result in increased food supply, habitat changes, changes in predatory activity, and so forth. Potential effects due to bioaccumulation by the bird per se or from a diet of soil microanimals could be significant. An important consideration is that the access of wild birds to sludge-treated lands cannot be restricted or controlled. An initial estimate of hazard may be made by correlating the hazard presented by heavy metal uptake to poultry.

No references were found in which the potential effects on wild mammalian species were evaluated. The considerations are the same as for avian species. Domestic animals could be used as models for hazard assessment, but potential effects on wildlife will probably be more severe than on domestic animals because of the inability to manage the consumption patterns of wildlife. Available research data indicates that a potential hazard does exist.

As the Fulton County project increases in size over time and land use patterns are altered, there probably will be significant changes in wildlife species. The first noticeable effect may be upon the growth and re-establishment of the Canada geese population, because these geese use the sink and pot holes endemic to nonreclaimed strip mine land for breeding. Another problem is the tremendous potential for mosquito breeding with subsequent anthropodborne disease transmission. This potential problem was verified (Pariyek, et al., 1967) through avian hemcocytrozon parasite infections determined by blood smears.

5. Human Health Implications

Potential indirect human health hazards are extremely difficult to assess. This section first describes the problems associated with this type of assessment, and then discusses the implications for human health of agricultural, conservation, and community-related use of the land on which sludge has been applied.

a. Difficulties of assessing hazards to humans - Evaluation of human health hazards resulting from mineral consumption presents five problems on which little research has been conducted. First, human susceptibility to specific mineral toxicities varies from person to person. This is genetically transmitted information which may cover many mitigating factors. Diet composition is a second problem. The variety of foods that is normally consumed tends to dilute high levels of one particular food component. The third factor is the efficiency of digestion and absorption by humans eating contaminated foods. This factor has genetic and dietary components. Fourth is the metabolic excretion and potential biotransformation of a contaminant which is absorbed, and the question of whether the metabolic half-life of the component is short (days) or long (years). Absorption and excretion factors control body loads of any component. The fifth factor is localization of a dietary component in specific organs or tissues, which has the net effect of multiplying existing body loads.

The most likely suspects for potential hazard are As, Cd, Pb, Hg, and Se. A joint FAO-WHO committee has set provisional limits on intake of Cd, Pb and Hg, which are shown in the first part of Table IX-16. The second part shows the permissible average food levels corrected for maximum water intake. These same calculations could be made for other elements, providing estimates were made for provisional intake, by using data presented in Table IX-17.

b. Land use influences on hazards to humans - Unrestricted and unmonitored use of plant produce or animal products from sludge-treated land in Fulton County presents a potential human health hazard. Environmental impacts at this point are minimal because sludge application rates are relatively low and the acreage developed for spreading is limited. Future hazards are also difficult to assess, as some of the necessary research is now in progress. The actual hazard level cannot be evaluated until sufficient data is available

Table IX-16. Provisional Recommendations for Cd, Pb and Hg (Adapted from WHO Technical Report Series 505, 1972)

Element	Acceptable Daily[1] Intake (mg/person)	Provisional Daily[1] Intake (mg/person)	Average Food[2] Level (mg/Kg)
Cd	none	0.07	0.024
Hg (total)	none	0.043	0.015
(methyl)	none	0.029	0.01
Pb[3]	none	0.43	0.15

Element	Maximum Water[4] Level (mg/l)	Maximum Daily Water Intake[5] (mg/person)	Average Food Level[2,6] Excluding Water (mg/kg)
Cd	0.01	0.025	0.016
Hg	0.005	0.0025	0.014
Pb	0.1	0.25	0.062

[1] Figure represents average daily intake over a 7-day averaging period.

[2] Assuming adult intake of 2.9 Kg/da.

[3] Does not apply for children.

[4] Manual for evaluating public drinking water supplies (1971), U.S. EPA.

[5] Assuming intake of 2.5l/day.

[6] Assuming H_2O levels to be at a maximum.

Table IX- 17. Recommended Limits for Drinking Water (EPA Manual for Evaluating Public Drinking Water Supplies, 1971)

Element	Maximum Allowable Limits (mg/l)
As	0.1
Ba	1.0
Cd	0.01
Cl	250
Cr	0.05
Cu	1.0
F	1.1-1.8*
Fe	0.3
Pb	0.05
Mn	0.05
Hg	0.005
Se	0.01
Ag	0.05
Na	270.
Zn	5.
NO_3^-	10.
$SO_4^=$	250.

*Dependent upon air temperature.

from soil, plant, and animal studies, especially dealing with element uptake and bioaccumulation. The actual hazard to humans will also stem from future use of reclaimed strip-mined land and agriculture practices. No valid assessment can presently be drawn due to the lack of information. A preliminary hazard analysis profile is shown as follows:

Worst Case

- Sale of land to farm operators who live on the premises and raise their own food with no monitoring or controls.
- Rural housing development where residents garden with no monitoring controls.

Best Case

- Land remains in hands of the MSDGC with rental to farmers, providing management and monitoring controls.
- Land developed for outdoor recreation, prairie preservation, and tree farms.

Average Case

- Land remains in hands of the MSDGC until hazards are defined; crop or pasture land is rented to farmers with management control.
- Land remains in hands of the MSDGC until hazards are defined; crop or pasture land is rented to farmers without management control, but all produce is sampled and tested prior to release.
- Development of confined livestock operations for beef cattle or swine; produce is sampled and tested prior to release.
- Land is developed as fish and wildlife preserve with hunting and fishing allowed after establishing zero hazard level; management and monitoring controls are provided.

Since this review is primarily oriented to assessing the potential for causing human health problems, current and hypothetical future land uses and controls are an important consideration. Current uses of the land include row crop production (corn and soybeans) and pasture (sudax and alfalfabrome) for beef cattle production. A small prairie conservation project is also underway. Future effects of land use can be considered under three classifications: agriculture, conservation and community.

Four general potential types of agricultural land use are pasture (beef or dairy), row crop (corn or soybeans), tree farms, and feedlots (beef or swine). Potential hazard from pasture development and grazing is great enough to warrant restricting it to sites where monitoring indicates no hazard. The same holds true for row crops. There would appear to be no hazard with tree farming. Use of the land for feedlots, assuming they are confined to well-drained sites with runoff containment, may be feasible for cattle but not for swine or other rooters. There are potential adverse effects from the use of crops or forages raised on project fields in the diet of animals grown for slaughter.

Conservational land uses include prairie restoration, hunting and fishing. A hazard to humans may exist with consumption of fish or wildlife from land spread with sludge. Until the safety of such produce is known, the harvest of fish and wildlife should be controlled. Aside from this restriction, there appears to be no hazard with respect to outdoor recreation.

However, rural housing development, on land applied with sludge,does present potential hazards great enough to warrant prohibition. A family living in a rural or semi-rural environment may obtain food from home gardening or raising domestic animals, in which case a majority of their food intake may originate from land treated with sludge.

C. MEASURES TO PREVENT OR MITIGATE INDIRECT HEALTH HAZARDS

As in the previous chapter, recommendations are presented here in terms of actions supporting a more thorough evaluation of the hazards and actions which would reduce known or suspected hazards.

1. Improved Evaluation of Hazards

An independent party, in cooperation with the MSDGC, Illinois EPA, U.S. EPA and University of Illinois, should collect and publish all existing and future information pertaining to the Fulton County project. Such data would be made available to all interested parties. A coordinated research and monitoring program for soils, crops and pasture, domestic animals and wildlife should then be formulated with the assistance of an advisory group representing the involved agencies and communities. Research findings should be made available at least one year in advance of any scheduled or unplanned change in agricultural and sludge spreading practices. The independent party should have the authority to confirm MSDGC analyses when necessary, and to require adequate sampling of soil and crops.

Several sections of fields should be set aside at the Fulton County project for evaluating:

- Sludge application rates and practices in demonstration fields in the immediate future
- Uptake of new or different plant varieties
- Changes occurring when sludge application is halted.

A comprehensive program should be developed for the evaluation of soil inorganic and organic elements:

- Prior to leveling
- After leveling
- After initial high sludge application rates
- On a yearly basis thereafter.

A similar program should be developed to evaluate inorganic and organic components of crops and animals raised at the Fulton County project. Workshops should be held to determine reasonable levels of contamination for animal and plant produce grown for commercial markets.

2. Reduction of Known or Suspected Hazards

Two measures in particular deserve attention:

- Increase the efficiency of wastewater treatment to reduce the concentrations of heavy metals in the sludge, perhaps through increased industrial pre-treatment.
- Minimize pathogen content at the time of application by longer retention in sludge lagoons and Fulton County holding basins.

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APPENDIX A: IEPA Water Pollution Control Permit

ILLINOIS ENVIRONMENTAL PROTECTION AGENCY
WATER POLLUTION CONTROL PERMIT

Permit Number: 1974-DB-444-OP

DATE ISSUED: March 7, 1974

PROJECT LOG NUMBERS: 3686-73, 3687-73, 3688-73, 174-74, 175-74

SUBJECT: FULTON COUNTY - Metropolitan Sanitary District of Greater Chicago Sludge Disposal Project - Comprehensive Operating Permit

PERMITTEE TO OPERATE: Metropolitan Sanitary District of Greater Chicago
100 East Erie Street
Chicago, Illinois 60611

Permit is hereby granted to the above designated permittee to operate water pollution control facilities described as follows:

The sludge transportation system, sludge storage facilities and sludge application fields previously approved under Permits #1971-DA-470, #1971-DA-487-1, #1972-DA-215, #1973-DB-1460-OP, #1973-DB-1460-OP-1, #1973-DB-1492, #1973-DB-1492-1, #1973-DB-1682, #1973-DB-1682-1, #1973-DB-1752, #1973-DB-2185 and #1974-DB-45-COP.

This Operating Permit expires on March 7, 1975.

The Application for Operating Permit and supporting documents approved by this Permit were prepared by Metropolitan Sanitary District of Greater Chicago and are identified in the records of the Illinois Environmental Protection Agency, Division of Water Pollution Control, Permit Section by the log numbers designated in the subject above.

This Permit renews and replaces Permit Numbers #1971-DA-470, #1971-DA-487-1, #1972-DA-215, #1973-DB-1460-OP, #1973-DB-1460-OP-1, #1973-DB-1492, #1973-DB-1492-1, #1973-DB-1682, #1973-DB-1682-1, #1973-DB-1752, #1973-DB-2185 and #1974-DB-45-COP, which were previously

(continued on Page 2)

READ ALL CONDITIONS CAREFULLY:

STANDARD CONDITIONS

Pertaining to both construction and operation permits.

1. If any statement or representation is found to be incorrect, this permit may be revoked and the permittee thereupon waives all rights thereunder.

2. During or after the construction or the installation of the sewage works, any agent duly authorized by the Environmental Protection Agency shall have the right to inspect such work and its operation.

3. The issuance of this permit (a) shall not be considered as in any manner affecting the title of the premises upon which the sewage works are to be located, (b) does not release the permittee from any liability for damage to person or property caused by or resulting from the installation, maintenance or operation of the proposed sewage works; (c) does not take into consideration the structural stability of any units or parts of the project; and (d) does not release the permittee from compliance with other applicable statutes of the State of Illinois, or with applicable local laws, regulations or ordinances.

4. Treatment works will be operated or supervised by a duly qualified sewage works operator certified under the Regulations of the Environmental Protection Agency.

5. The treatment works or wastewater source covered by this permit shall be constructed and operated in compliance with the provision of the Environmental Protection Act and Chapter 3 of the Rules and Regulations as adopted by the Illinois Pollution Control Board.

6. Plans, specifications and other documentation submitted shall constitute a part of the application and when approved shall constitute part of the permit.

7. This Permit may not be assigned or transferred without a new permit from the Illinois Environmental Protection Agency.

Pertaining only to construction permits.

1. There shall be no deviations from the approved plans and specifications unless revised plans, specifications, and application shall first have been submitted to the Environmental Protection Agency and a supplemental written permit issued.

2. The installation shall be made under the supervision of an inspector, who is familiar with the approved plans and specifications provided by and approved by the owner, and said inspector shall require that construction complies with the plans and specifications approved by this Agency.

3. Unless otherwise stated by Special Condition, construction must be completed in three years for treatment works and two years for sewers and wastewater sources.

4. Unless otherwise stated by Special Condition, the issuance of this permit shall be a joint construction and operation permit provided that:

   a) All standard and Special Conditions, are complied with.

   b) This Agency is notified within ten (10) days, respectively, of the start of construction and the date of testing and start-up of full operation.

   c) The submission of operating reports of the treatment works covered under this permit shall be at a frequency specified by this Agency.

   d) The operation permit shall expire one year from the date of start-up of operation.

   e) At least 90 days prior to the expiration date of the operation permit, the permittee shall apply for a renewal of the operation permit.

This permit is issued in accordance with the Illinois Environmental Protection Act of 1970 and the Chapter III Water Pollution Regulations adopted by the Illinois Pollution Control Board in March of 1972.

TRW:CWF:il
cc:Grants & Tax, Region II & III
Fulton Co. Health Dept., Fulton Co.
Bd. of Supervisors, MSDGC-R.Rimkus
H.McMillan
J.Braxton

DIVISION OF WATER POLLUTION CONTROL

WHBusch
William H. Busch
Manager, Permit Section

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issued for the herein permitted facilities.
The Standard Conditions of issuance of this Permit are itemized on Page 1. (Special Conditions applicable are itemized below).

This Permit is issued subject to the following Special Conditions. If such Special Conditions require additional or revised facilities, satisfactory engineering plan documents must be submitted to this Agency for review and approval for issuance of a Supplemental Permit.

SPECIAL CONDITION #1: Upon termination of the sludge transportation activities, the Sanitary District shall be responsible for the proper removal and disassembly of non-permanent equipment for which this permit is issued.

The proper disassembly includes, but is not limited to, the cleaning of the pipeline so no sludge residue will escape to any area other than the properly permitted holding basins.

SPECIAL CONDITION #2: This permit is issued on the basis that any surveillance activity by the staff of this Agency does not relieve the applicant from sole responsibility for establishing and continuing a surveillance program for monitoring and detecting any discharge of waters which do not meet the applicable provisions of the Environmental Protection Act or the Rules and Regulations of the Pollution Control Board.

SPECIAL CONDITION #3: The sludge transported to the Fulton County site shall be adequately digested and suitable for land application based on the parameters presented in Table 2 of the report entitled "Quality of Digested Sludge Suitable for Land Application" prepared by the Research and Development Department of the Metropolitan Sanitary District of Greater Chicago, dated July 23, 1973.

SPECIAL CONDITION #4: This Permit does not relieve the District of sole responsibility for the existing discharges to the waters of the State which may have occurred through mining activity or any other past activity in this area, which do not meet the applicable provisions of the Environmental Protection Act or Illinois Pollution Control Board Rules and Regulations.

SPECIAL CONDITION #5: The District shall maintain a minimum of four (4) feet freeboard in the lagoons at all times.

SPECIAL CONDITION #6: The District must submit to this Agency, in addition to the quarterly reports currently submitted, a monthly report. The operational information to be contained in the monthly report must be satisfactory to the Agency and the report must be submitted in triplicate within 20 days of the end of the month covered by the report.

SPECIAL CONDITION #7: Up to date sampling data and operational information to be used in the monthly reports must be available for inspection by this Agency's personnel at the Fulton County Site.

SPECIAL CONDITION #8: If for any reason the District abandons this project, it is required that the sludge holding basins be emptied of sludge and the sludge be disposed of in a manner which will not cause pollution.

SPECIAL CONDITION #9: The effluent discharged from any retention basin approved under this Permit must meet the applicable effluent requirements for discharge to the waters of the State as required by Illinois Pollution Control Board Rules and Regulations Chapter 3. The point of discharge to the waters of the State is considered to be the overflow structure of each of the retention basins.

SPECIAL CONDITION #10: This Permit is issued with the condition that the following contaminant concentrations are considered to be background values and the numerical effluent standards shall be considered met at the designated effluent sampling point described in Special Condition #9 when the background concentration plus the allowable regulatory concentration is greater than the measured concentration for the appropriate parameter:

	Total Suspended Solids	BOD	Fecal Coliform
			$\frac{FC}{100\ ml}$
arithmetic mean	61.7	2.75	-
std. dev.	87.3	1.48	-
geometric mean	-	-	94.3

SPECIAL CONDITION #11: In order to provide storage for the capture of a 100 year frequency storm, the District shall remove waters from the retention basins as soon as practicable after a storm. This Agency shall require that records be kept of precipitation and the approximate amounts of runoff pumped back to the fields or discharged and that these results be submitted along with the monthly operation reports.

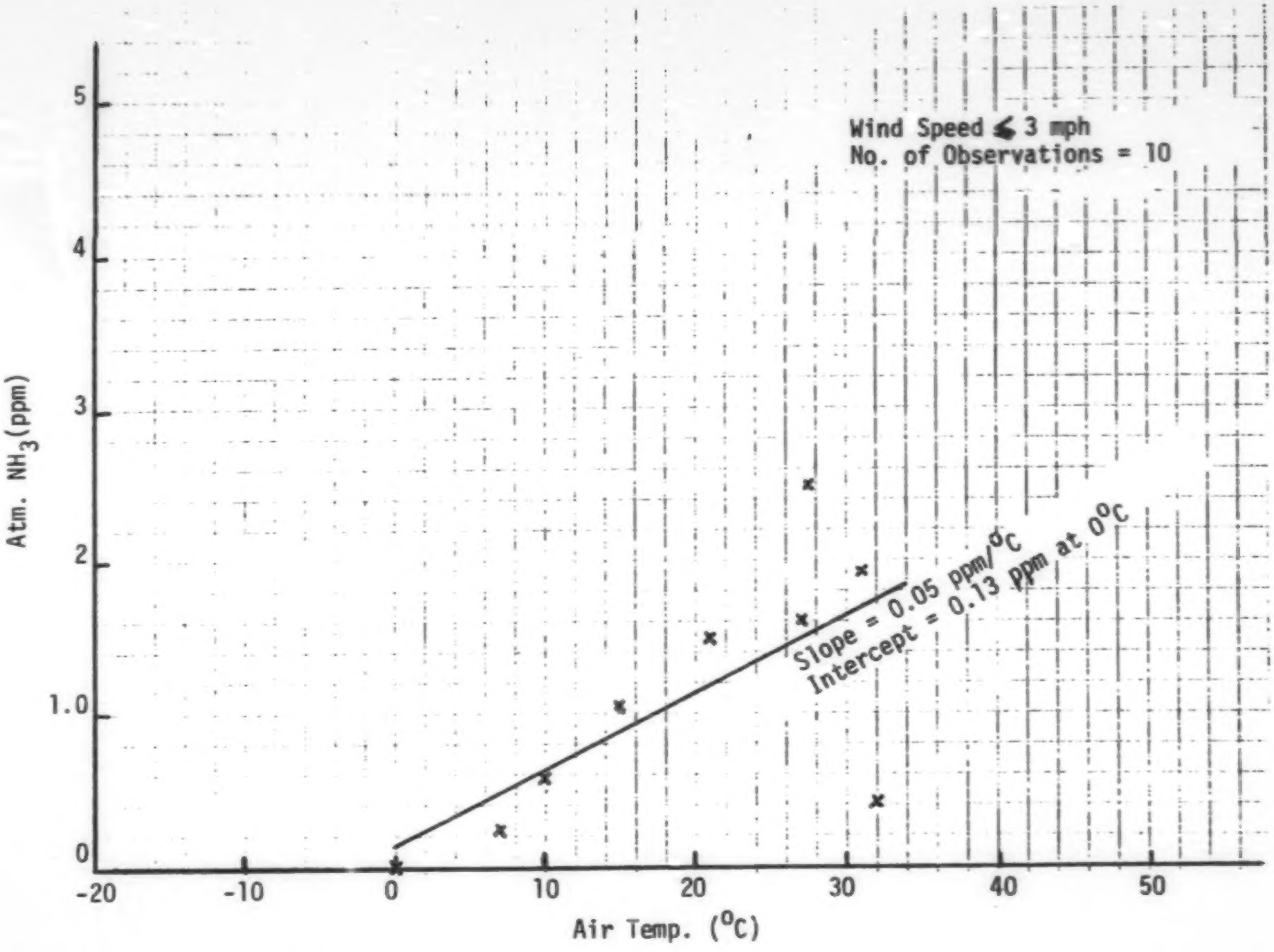
SPECIAL CONDITION #12: The District shall maintain at least one control plot on which crops are grown without the application of sludge in order to provide a continuing source of data regarding the runoff from such fields. The runoff from the control plot shall be monitored and the results submitted to this Agency as a part of the monthly operation reports.

SPECIAL CONDITION #13: The District shall restrict its procedures of land application to subsurface injection or ridge and furrow application whenever practical.

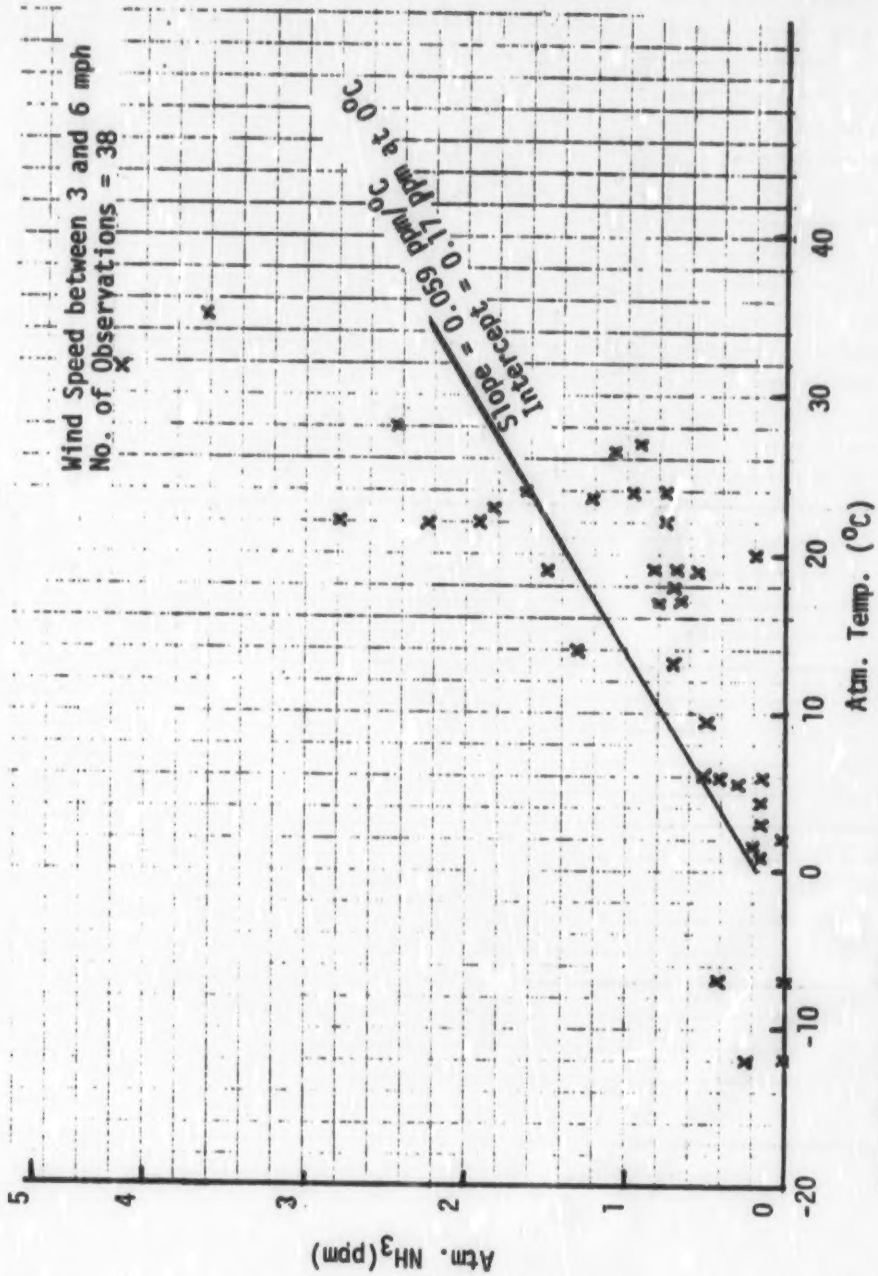
SPECIAL CONDITION #14: The District shall monitor the metals content of the crops harvested from the sludge application fields and shall submit the results to this Agency in the monthly operation reports.

SPECIAL CONDITION #15: This Permit includes the construction of the supernatant piping around the sludge holding basins.

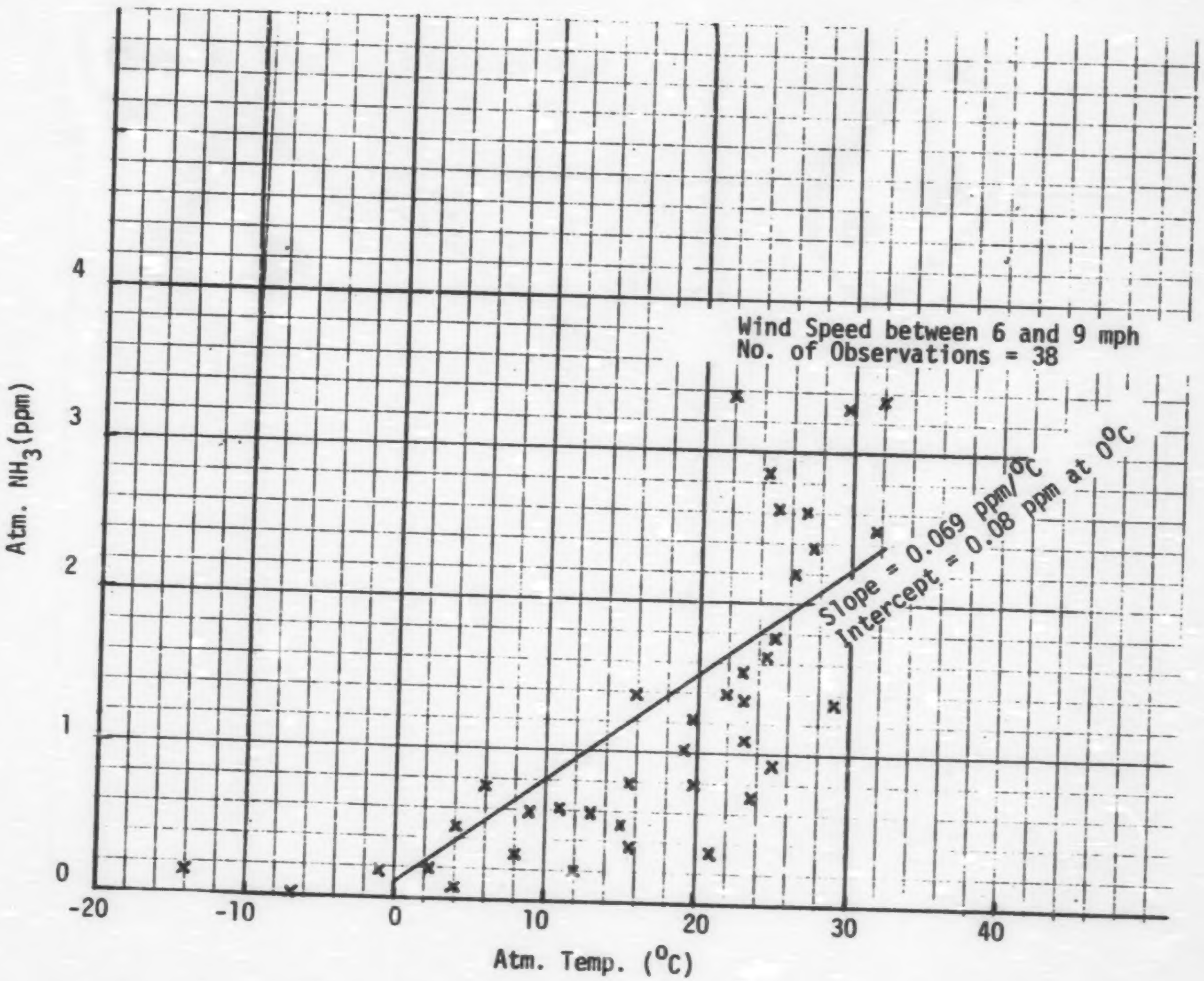
APPENDIX B: Atmospheric Ammonia Concentrations, by Temperature and Windspeed



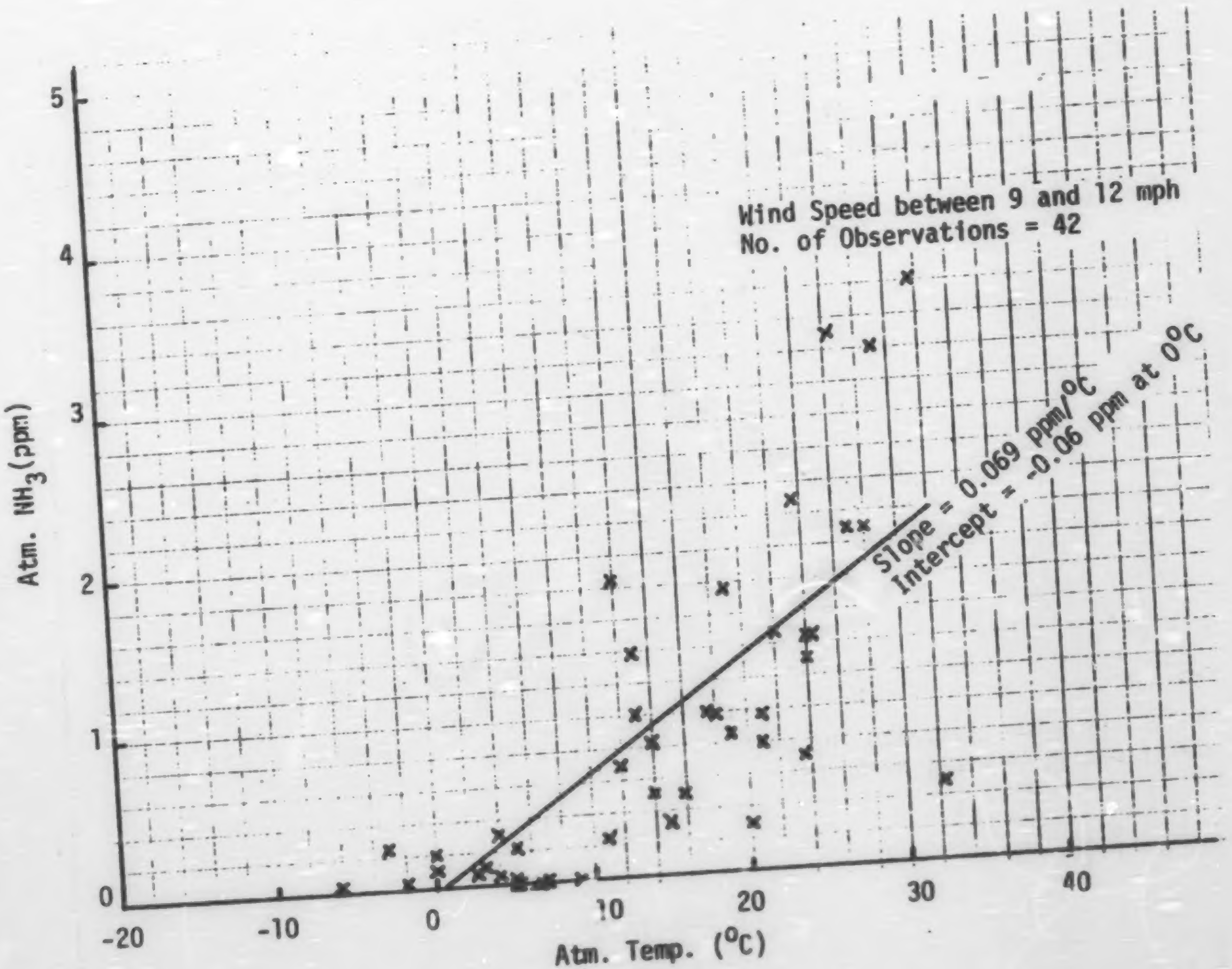
Data Source: MSDGC, 1972a through 1975g



Data Source: MSDGC, 1972a through 1975g



Data Source: MSDGC, 1972a through 1975g



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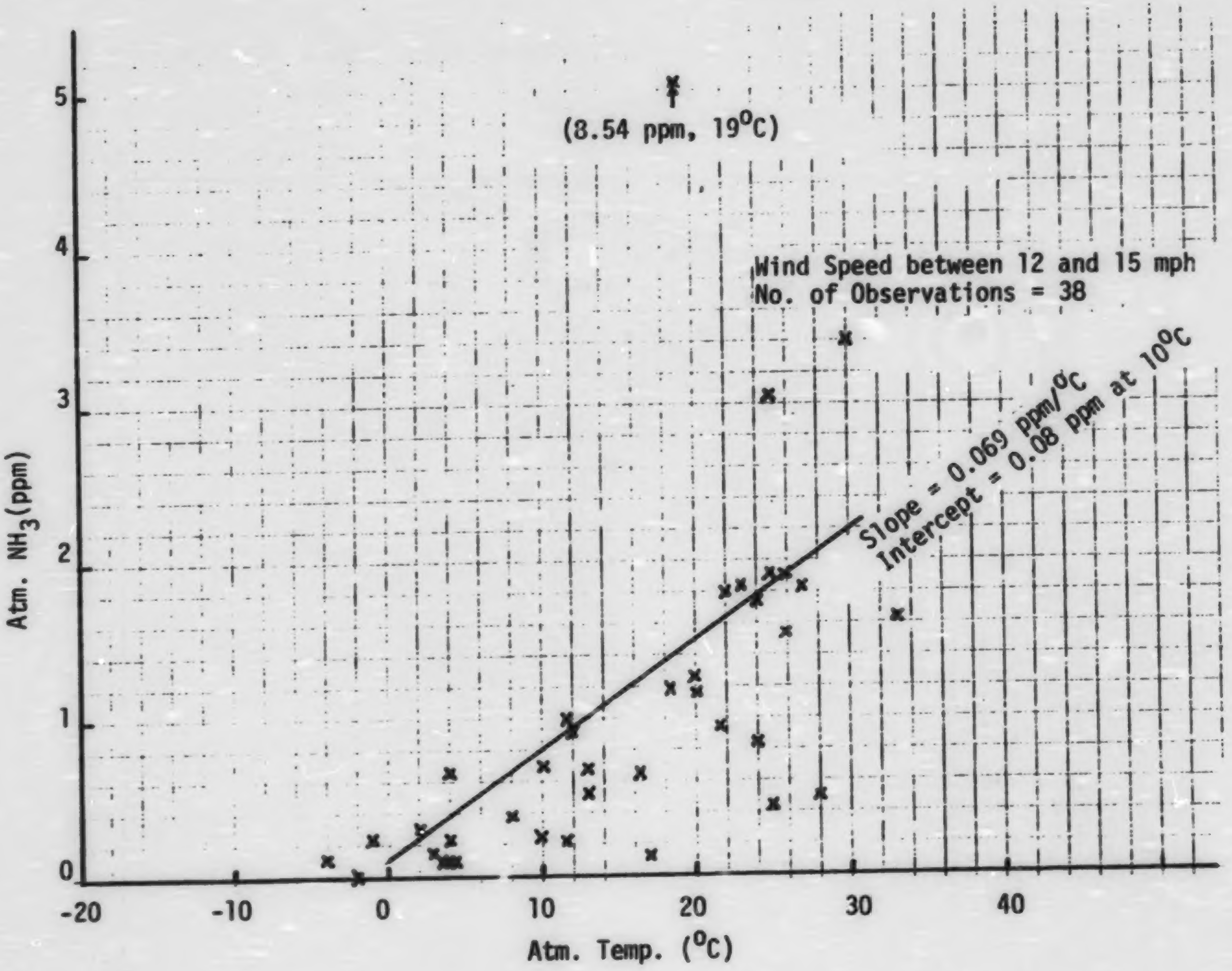
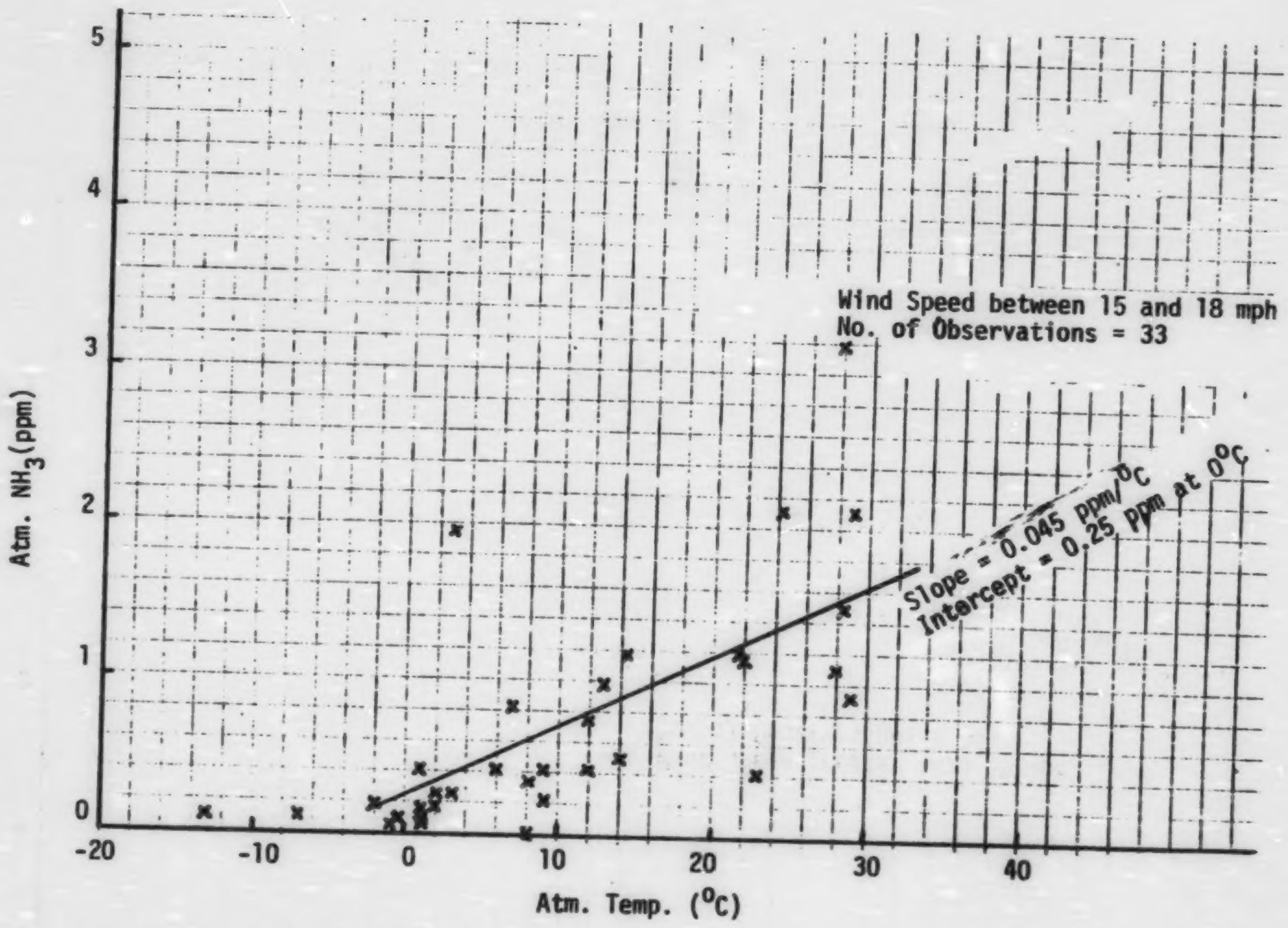
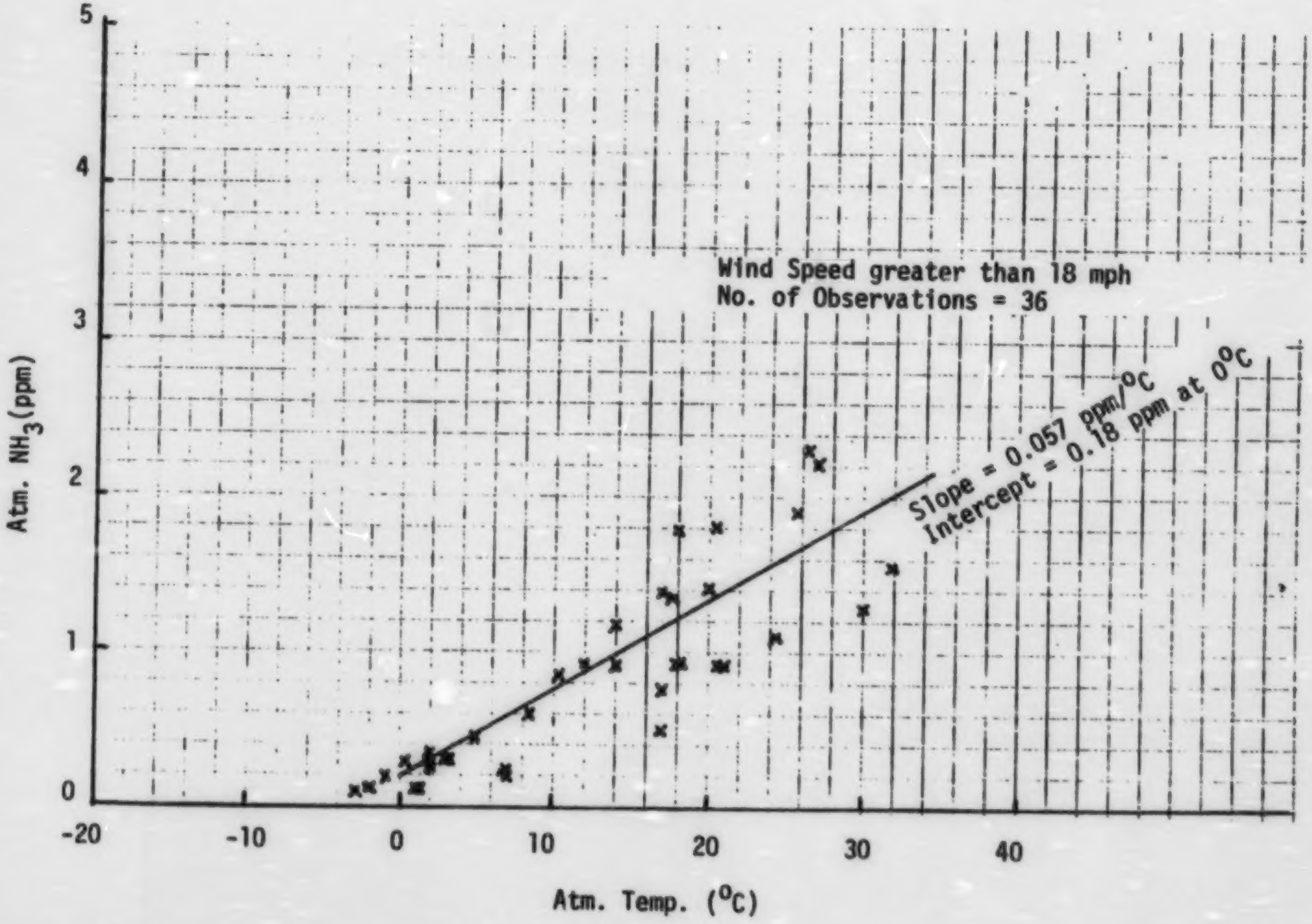


Data Source: MSDGC, 1972a through 1975g

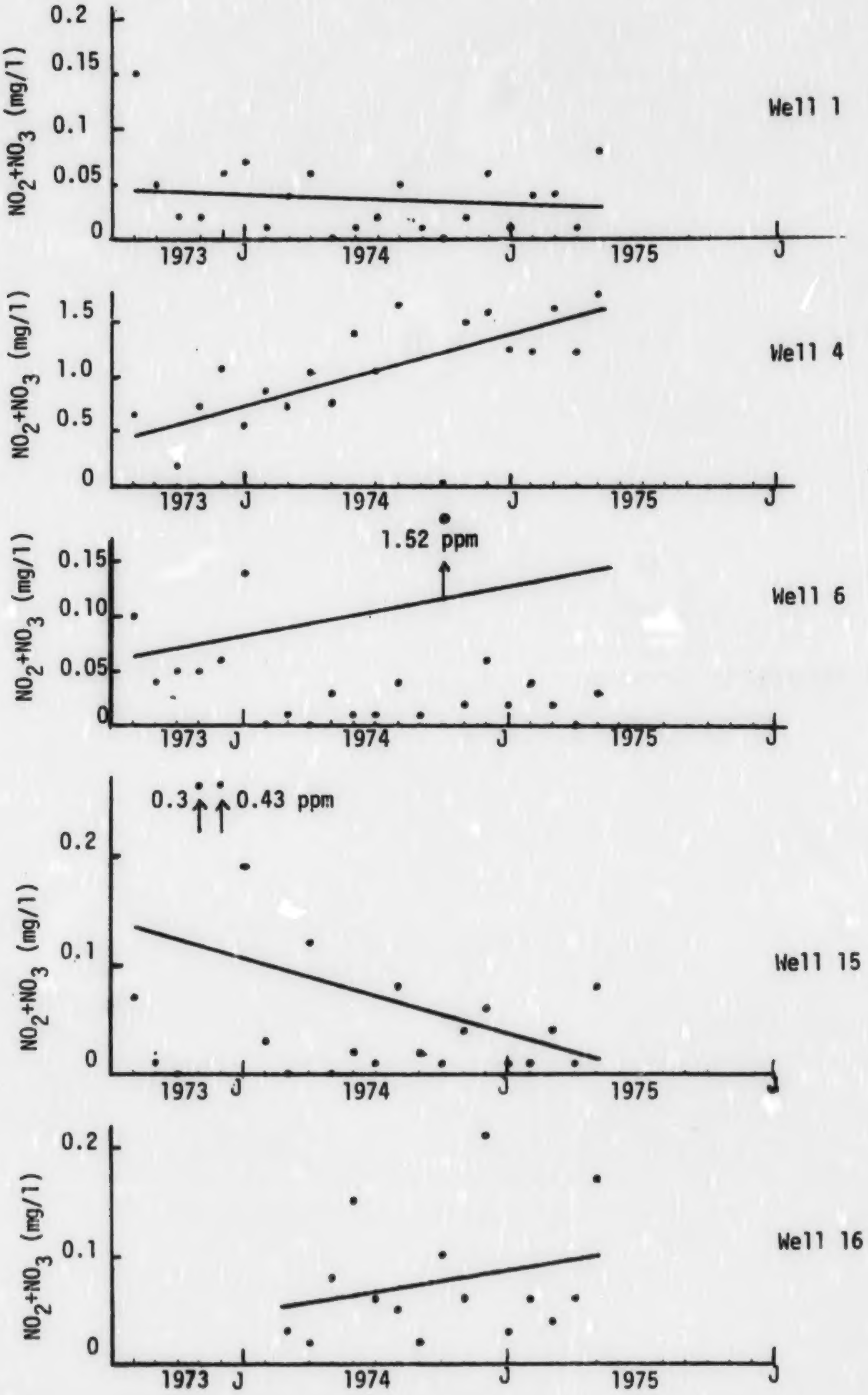


Data Source: MSDGC, 1972a through 1975g

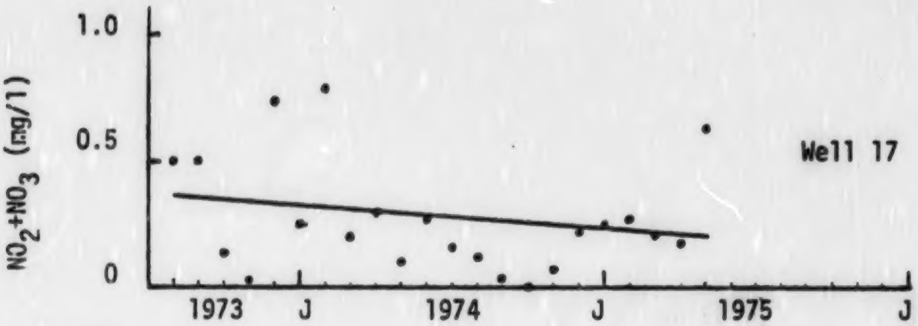


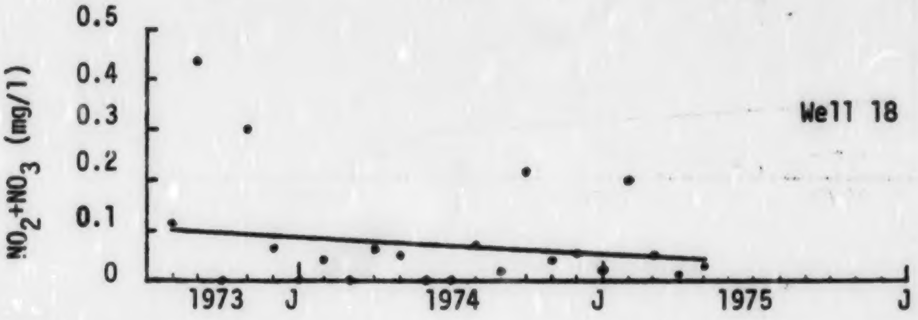
Data Source: MSDGC, 1972a through 1975g

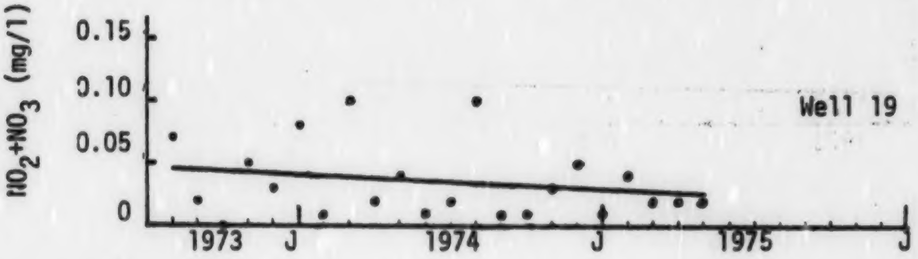
APPENDIX C: Trends of Nitrite and Nitrate Nitrogen in Wellwater

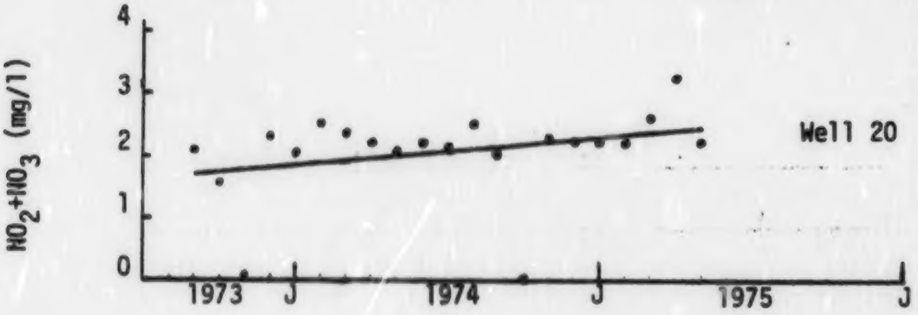


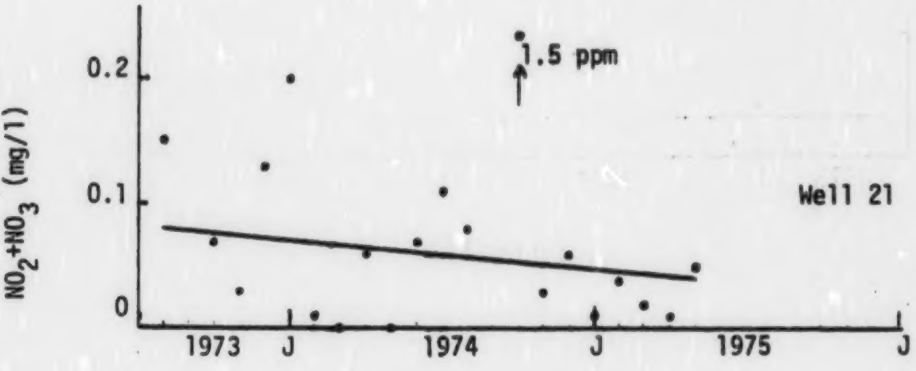
Trend of Nitrite and Nitrate Nitrogen for Background Wells (MSDGC, 1972a through 1975g; Enviro Control, Inc., 1976)


1.0
0.5
0
NO_2+NO_3 (mg/l)
Well 17
1973
J
1974
J
1975
J

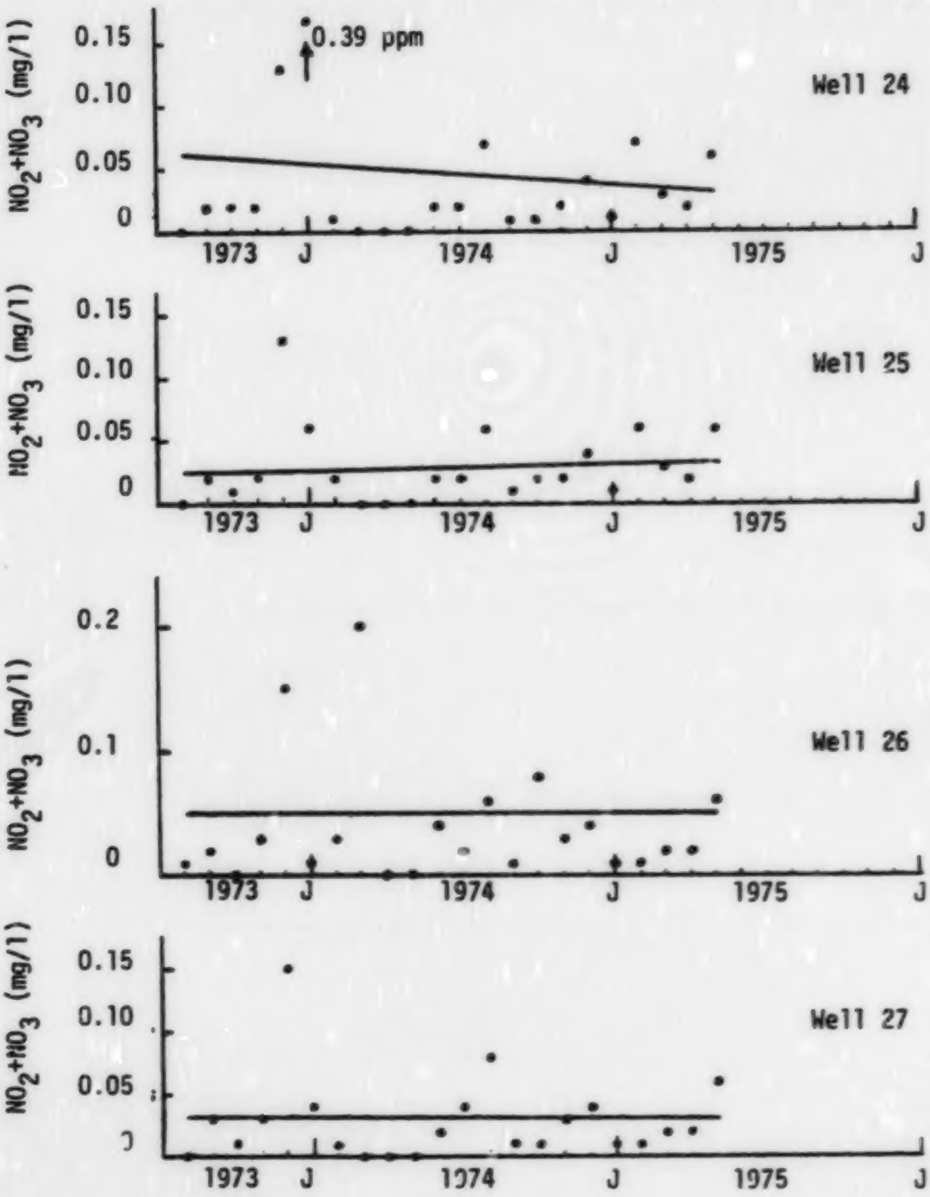

0.5
0.4
0.3
0.2
0.1
0
NO_2+NO_3 (mg/l)
Well 18
1973
J
1974
J
1975
J


0.15
0.10
0.05
0
NO_2+NO_3 (mg/l)
Well 19
1973
J
1974
J
1975
J

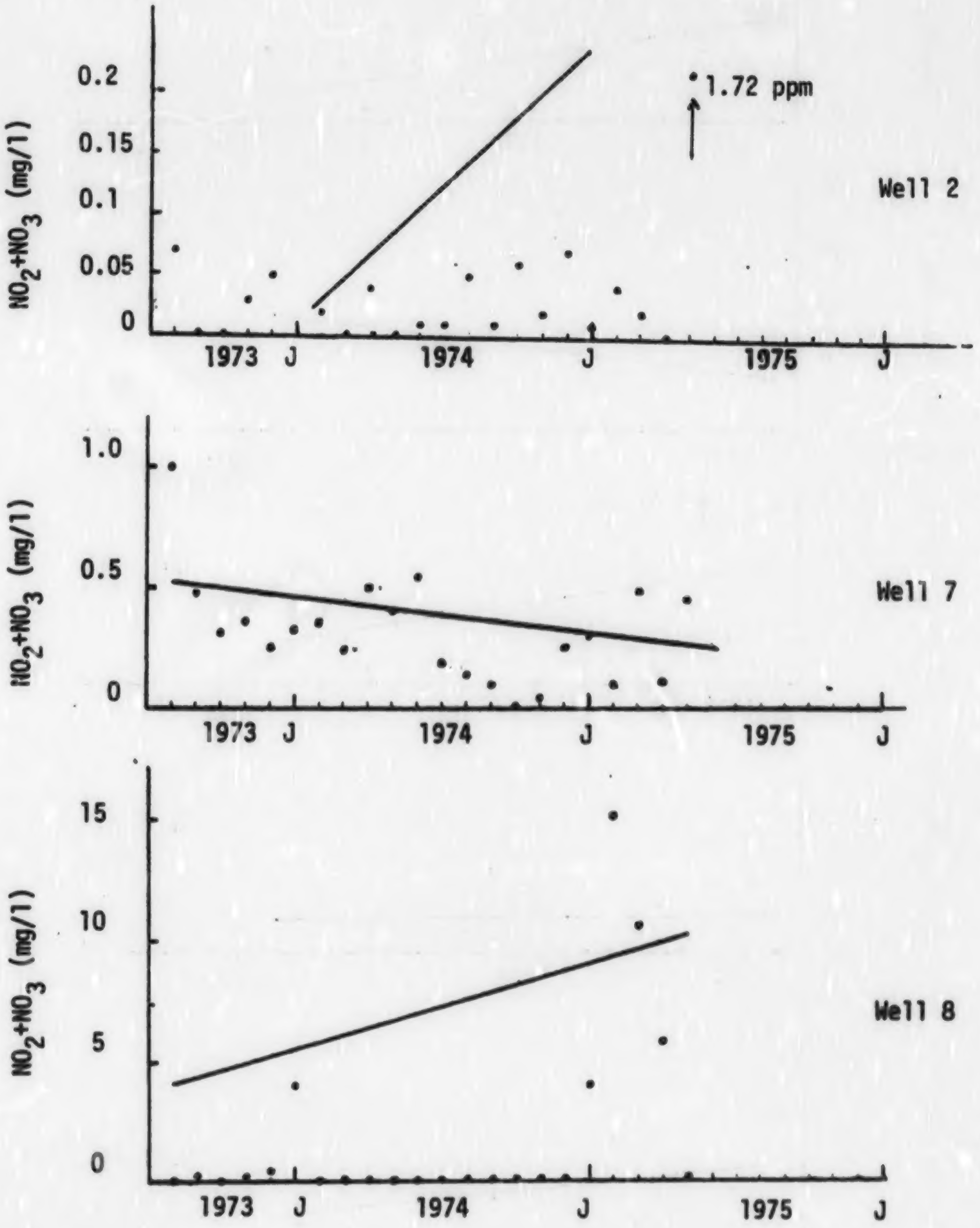

4
3
2
1
0
NO_2+NO_3 (mg/l)
Well 20
1973
J
1974
J
1975
J


0.2
0.1
0
NO_2+NO_3 (mg/l)
1.5 ppm
Well 21
1973
J
1974
J
1975
J

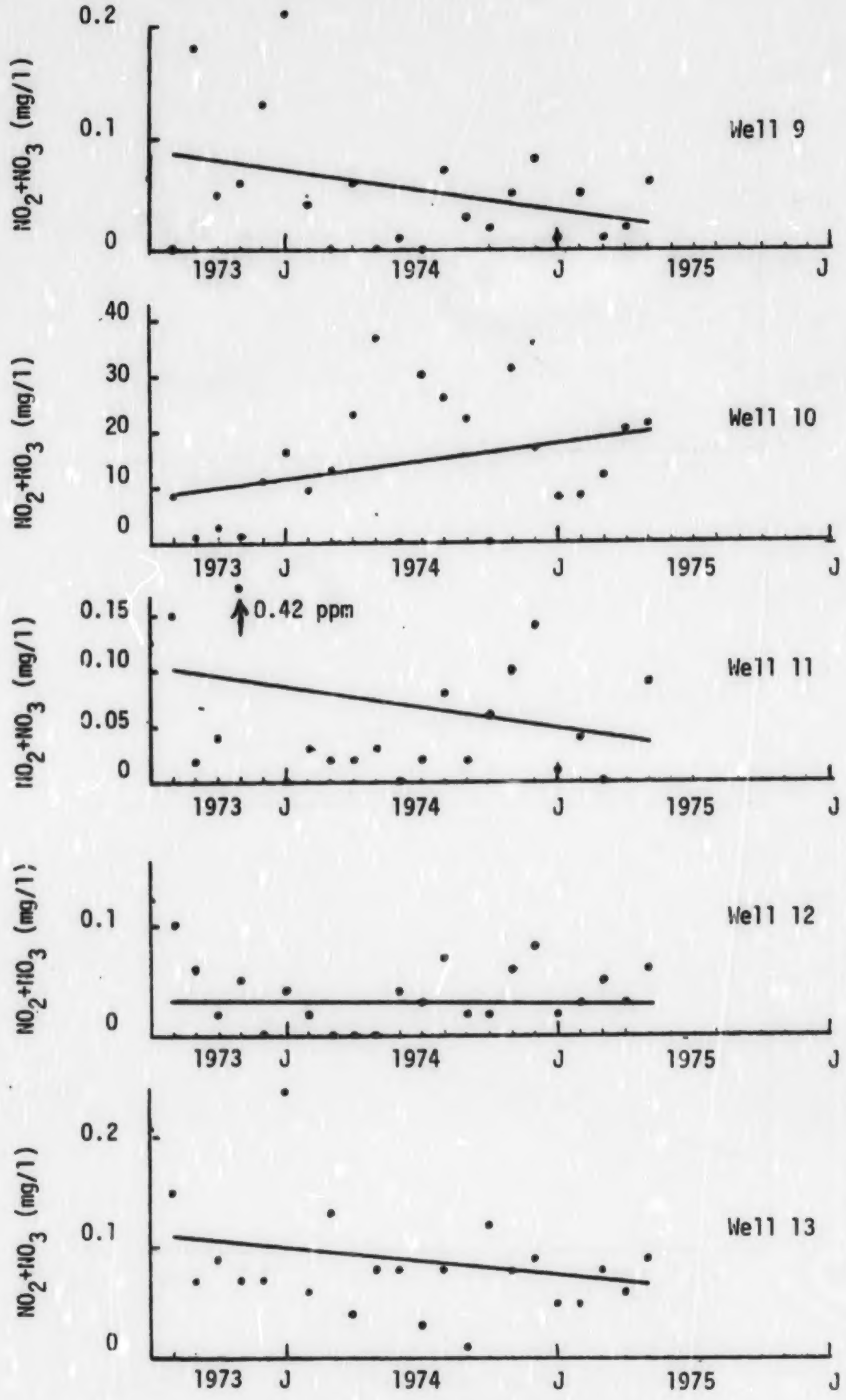
(continued)


NO$_2$+NO$_3$ (mg/l)
0.15
0.10
0.05
0
0.39 ppm
Well 24
1973
J
1974
J
1975
J
NO$_2$+NO$_3$ (mg/l)
0.15
0.10
0.05
0
Well 25
1973
J
1974
J
1975
J
NO$_2$+NO$_3$ (mg/l)
0.2
0.1
0
Well 26
1973
J
1974
J
1975
J
NO$_2$+NO$_3$ (mg/l)
0.15
0.10
0.05
0
Well 27
1973
J
1974
J
1975
J

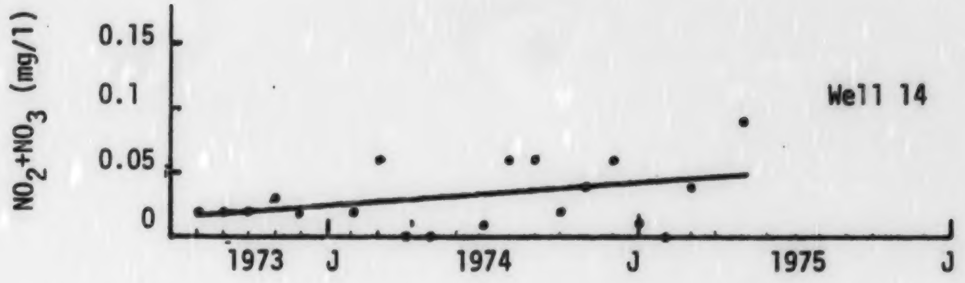
(continued)

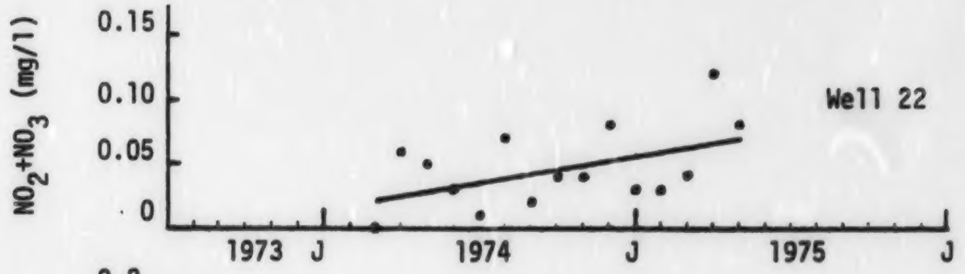


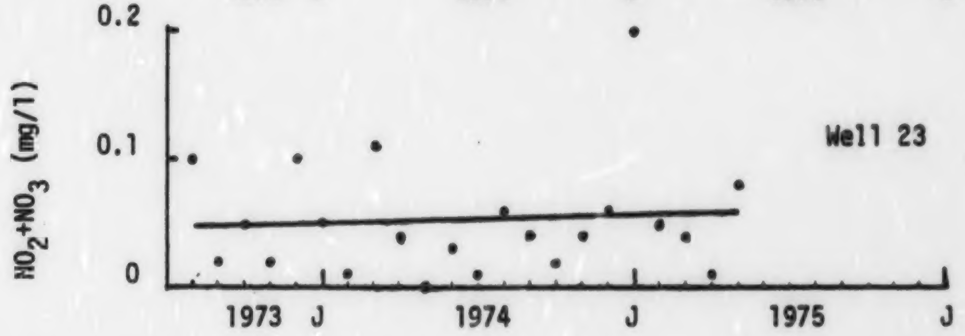
Trend of Nitrite and Nitrate Nitrogen of Possibly Contaminated Wells or Springs (MSDGC, 1972a through 1975g; Enviro Control, Inc., 1976)

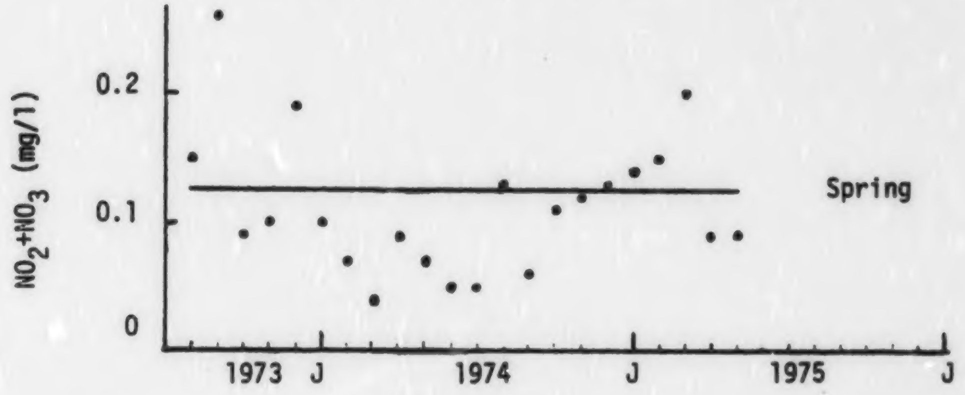

Well 9
NO$_2$+NO$_3$ (mg/l)
0.2
0.1
0
1973
J
1974
J
1975
J
Well 10
NO$_2$+NO$_3$ (mg/l)
40
30
20
10
0
1973
J
1974
J
1975
J
Well 11
NO$_2$+NO$_3$ (mg/l)
0.42 ppm
0.15
0.10
0.05
0
1973
J
1974
J
1975
J
Well 12
NO$_2$+NO$_3$ (mg/l)
0.1
0
1973
J
1974
J
1975
J
Well 13
NO$_2$+NO$_3$ (mg/l)
0.2
0.1
0
1973
J
1974
J
1975
J

(continued)


NO$_2$+NO$_3$ (mg/1)
0.15
0.1
0.05
0
1973
J
1974
J
1975
J
Well 14


NO$_2$+NO$_3$ (mg/1)
0.15
0.10
0.05
0
1973
J
1974
J
1975
J
Well 22


NO$_2$+NO$_3$ (mg/1)
0.2
0.1
0
1973
J
1974
J
1975
J
Well 23


NO$_2$+NO$_3$ (mg/1)
0.2
0.1
0
1973
J
1974
J
1975
J
Spring